MODERN METHODS

OF

WATER PURIFICATION

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PREFACE TO THE SECOND EDITION

So very considerable progress has been made in the methods of water purification during the two years that have passed since the publication of this work, that an additional chapter has been devoted to the description of processes which have recently come into prominence. The sterilization of water-supplies that may be liable to contamination is now occupying the attention of municipal authorities far more actively than at any previous time, and large developments in this direction may be confidently anticipated. In America the application of hypochlorite has been adopted at many important stations, and on the Continent the ozone treatment is making rapid headway. While neither of these systems has as yet received any large measure of support in Great Britain, leading authorities on water purification have expressed themselves favourably with regard to both. As an alternative to ozone and hypochlorite, we have Dr. Houston's Excess Lime Process, which is certain to receive very attentive consideration in the near future.

The question of sterilization has been fully entered into in Chapter XIV., where typical installations and recent improvements in purifying appliances are described. The whole book has also been carefully revised and brought up to date, so as to present to the reader the actual condition of the methods of water treatment as they now exist.

J. D.
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April, 1913.

PREFACE TO THE FIRST EDITION

The favourable reception which was generally accorded to a paper by one of the authors of this volume, read before the Institution of Mechanical Engineers in London, on "The Filtration and Purification of Water for Public Supply," has been the motive for the preparation of a fuller treatment of the subject. As the methods now recommended for the purification of water are both numerous and varied, it seems opportune to review the different processes, and to consider how far their usefulness is determined by the character of the water-supply.

Much has been done to this end, though often in a more or less detached way, by the existing periodical literature dealing with water engineering and public health. In addition, there are standard works on the purification of water of recent date in different languages, the reports of the State Boards of Health in America, also of the Imperial Board of Health in Berlin, and of the Conseil d'Hygiène in Paris, and the very valuable reports of research work done at the laboratories of the Metropolitan Water Board.

From these sources mostly it is that water authorities and their officials are able to keep in touch with modern developments and with experimental work in the domain of water purification. In the present volume an attempt has been made to bring together in a clear and compact way the materials

with regard to which those interested in the treatment of water should have reliable and up-to-date information. To compress into a work of moderate dimensions even a summary of all the useful and interesting facts that have come to light in recent years with reference to water purification would have been an impracticable task, and less appropriate to the object in view than to devote attention to methods which appear to stand in the forefront of modern practice.

Of first interest at the present time are the modern views on the theory and practice of sand filtration, and the material progress that has been made in raising the efficiency of this widely-used process of purification by help of improved construction and scientific management. It has therefore been thought desirable to describe fully how the sand-filter does its work, so that those who find that it does not act as efficiently as they might have expected may be guided in the inquiry into the cause of the defect and in the application of a remedy. There are limits to the efficiency of sand-filters under normal conditions, and as public opinion proceeds to favour more and more stringent standards of purity in drinking water, irrespective of the quality of the source, the greater will be the strain on the resources and skill of the engineer who seeks to adapt the sand-filter to the purification of water.

Advances in the method of treating water have followed one or other of three different lines. Arising from a knowledge of the influence of coagulants on turbid waters, there has come into use a large variety of mechanical filters, which in many cases deal rapidly and effectively with waters that are hardly amenable to treatment in the older fashion. Again, the urgency of excluding pathogenic germs from service water has favoured the adoption of some form of sterilization, either by fluid bactericides or by ozone. Lastly, well-marked pro-

gress has been made in preparing crude waters for a final sand filtration by means of successive prefiltration, whereby the effluent comes to attain great uniformity of quality, with freedom from undesirable bacteria.

These matters have been dealt with in some detail. The discussion of them naturally brings into prominence other topics which directly bear on modern improvements. Such are the storage of raw water, the care of filtered water and its distribution, the vegetable and animal life in reservoirs and filter-beds, and the methods at the disposal of the water manager for testing the purity of the treated water.

The authors have been engaged for a considerable time in experimental work in the purification of water, and have visited many of the most important installations at home and abroad. But it would have been impossible to prepare this treatise without obtaining permission to make full reference to the work of many eminent authorities. This permission has been very cordially granted in all cases, and the authors would desire to express their indebtedness to Dr. A. C. Houston, Director of Water Examination, Metropolitan Water Board; to Director J. M. K. Pennink, Amsterdam; to Dr. Kemna, of Antwerp; to Professor Dr. Zacharias, of the Plön Biological Institute; M. de Frise, Av. du Bois de Boulogne; Mr. W. Clemence, M.I.Mech.E., London; and MM. Puech-Chabal, Paris.

Their acknowledgments are also due to the makers of mechanical filters described in the book, and to the patentees of devices for regulating the introduction of coagulants, and to the owners of many other special appliances. All of these have willingly accorded assistance in the preparation of the descriptive part, and have in many cases provided special diagrams. For permission to reproduce Figs. 47, 48, and 50 from the *Annalen der Physik*, the authors are under obligation

to the publisher, J. A. Barth, Leipzig. Lastly, to the Council of the Institution of Mechanical Engineers the authors are indebted for permission to reproduce Figs. 3, 25, 53, 58, 59, 61, and 62 from the Proceedings of the Institution.

A bibliography of water purification is given in the Appendix, and while all the works noted have been consulted, the valuable contributions on the treatment of water which have appeared from time to time in *Water*, *Wasser und Abwasser*, *The Transactions of the British Association of Water Engineers*, *Engineering*, *The Sanitary Record*, *Gesundheits Ingenieur*, and the *Revue d'Hygiène* have been particularly helpful and instructive.

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CONTENTS

CHAPTER I

INTRODUCTORY

CHAPTER II

SOURCES OF SUPPLY

CHAPTER III

STORAGE

CHAPTER IV

CONSTRUCTION OF RESERVOIRS AND CARE OF FILTERED WATER

CHAPTER V

SAND-FILTRATION

CHAPTER VI

THE MANAGEMENT OF SAND-FILTERS

CHAPTER XI

THE TESTING OF WATER—*Continued*

CHAPTER XII

THE PROBLEMS OF DISTRIBUTION

CHAPTER XIII

THE PROBLEMS OF DISTRIBUTION—*Continued*

CHAPTER XIV

RECENT ADVANCES IN STERILIZATION

APPENDIX

USEFUL CONSTANTS AND DATA RELATING TO WATER FILTRATION AND MEASUREMENTS

LIST OF ILLUSTRATIONS

MODERN METHODS OF WATER PURIFICATION

CHAPTER I

INTRODUCTORY

DESIGNED to render an account of modern developments in the theory and practice of water purification, this work is an attempt to bring under the notice of Water Authorities and their officials the most efficient appliances for the treatment of water, together with the details of working and costs of construction and management.

The present is a time of great activity in the domain of water purification. At no period have county and municipal authorities been more keenly interested in the combat between medical science and epidemic disease. The germ origin of infectious maladies being now no longer regarded by the community as a pure theory, but as a certain fact, the whole weight of public opinion gravitates towards one central aim. Bar the avenues by which the causes of bodily ailments approach the individual, set a watch on the supply of comestibles and of water, upon the very air of the streets and of the habitations: therein lies the true method of safeguarding the health of the community. If any evidence were required of the quickening of public opinion in recent times with reference to the expediency of striking at the roots of infection, it would be found in the numerous appointments of Medical Officers of Health and Sanitary Inspectors, in the compulsory isolation of sufferers from epidemic diseases, and in the increased attention that is now being paid to the bacteriological examination of the water supply. Practical science has become the handmaiden of social life. They cannot be dissociated without obscuring the way to efficiency. With the growth of expert knowledge, the diffi-

culties which beset the question of public health will be handled with increasing success.

Among these problems there is, perhaps, not one more important than that of providing an adequate supply of wholesome water for household and dietetic use. The sin of introducing disease into the midst of a population has so frequently been laid to the charge of the drinking water that it has become almost a necessity to place that commodity beyond the range of suspicion.

"Nearly all great outbreaks of diseases, both in this country and elsewhere," said the President of the Institute of Sanitary Engineers at the meeting in 1908, "have been associated with certain conditions of the water-level in the soil." Further, he drew attention to the extraordinary circumstance that the death-rate of children under five years—after excluding diarrhœa cases—is inversely proportional to the quantity of water present year by year in the soil. Now, these statements may not be incontrovertible, but that there is a large element of truth in them cannot be doubted. Typhoid fever is associated with the fall of the year, when a more copious rainfall begins to wash surface impurities and germs that have been thriving near the surface down to the deeper strata from which drinking water is drawn. The periodicity of the visits of this fever is so noticeable in America that it goes by the name of "fall fever." That a replenishment of the hospitals with enteric patients takes place regularly in Britain in the months of October and November is but too well known to the medical profession.

We need dwell no longer on this point. Water is not by any means the only vehicle by which the seeds of disease are conveyed to men, but its universal use in the household, the part it plays in the preparation of food, its use as a beverage at all hours of the day, confer upon it, when polluted, far-reaching powers for mischief. A vitiated supply of milk, distributed from a particular dairy, may be responsible for a greater percentage of victims among the consumers of it, but the taint will probably reach no more than a small fraction of the community. Bad water, on the other hand, exercises its influence on all—all ranks and all ages. Those who escape its evil effects owe their immunity to a vigorous constitution or to accidental circumstances. The stricken are those whose

general tone is below par. Even the perfectly healthy suffer when the degree of pollution is serious. Further, if the germs of disease be present in water drunk, no particular individual can solace himself with the thought that he is safely entrenched against their attack. The danger is real; the risk cannot be gainsaid.

The cognizance of the fact that pure water is not only desirable, but also essential, in the interests of health, is no new thing; for history informs us that water from springs and wells was sought for by preference, and that in remote ages water was carried from distant uplands to certain important cities. What is new is the realization of the fact that water which was generally accepted as unexceptionable, either because it was drawn from deep wells or because it had been passed through sand filters, may be very far from pure, under all conditions and at all seasons.

Filters which are efficient when tested in the ordinary way may become unreliable when the conditions are varied in a manner adverse to their prearranged operations, and also when they are handled unskilfully. The removal of sediment by the filter may appear satisfactory, but unless the sand surface be properly filmed, or the efficiency of the bed otherwise established, obnoxious germs may be passing through in thousands. There is matter for reflection in the fact that certain authorities are so careful with regard to the proper formation of this film that they do not hesitate to allow the effluent from a freshly sanded filter to run to waste for two or three weeks, before turning it into the service reservoir. In general practice, however, the time allowed for filming is limited to forty-eight hours or less.

There is probably no system of purification yet devised that can claim to be safe and reliable without constant supervision and periodical examination of the results of its working. Rapid mechanical filters, with or without coagulants, and ozone purifiers, require to be adjusted to the condition of the incoming water. There is but one way of ascertaining whether the appliances are doing the work expected of them, and that is examination of the effluent, consistently repeated at appropriate intervals during the operation of the filters.

Formerly it was the custom to attach supreme importance to the chemical analysis of water, because it was supposed,

somewhat erroneously, that the percentage of certain ingredients indicated definitely the volume of sewage or other foul liquid that had made its way into the supply. It is not to be questioned that the presence of an undue percentage of organic matter should raise suspicion, and lead to immediate inquiry into its origin. "But," says Wanklyn,* "the nitrates and nitrites have been erroneously regarded as measuring the defilement of water"; and other authorities of note hold that the presence of considerable amounts of organic matter does not warrant the analyst in saying that the water is bad, while the absence of the same matter does not guarantee bacteriological purity. From his quantitative measurements, the chemist may entertain strong presumptions, but certainty escapes him. A reliable test has been put into his hands in consequence of the progress of that branch of natural science which deals with microscopic germs. Not only does this test remove all uncertainty, but it is also extremely delicate, so that the remotest possibilities of any given supply causing mischief can be detected. At length it would seem that water authorities in general are approaching the question of water purification from the right standpoint. It is generally the case that sand filters do little to alter the chemical character of a supply; they may do a very great deal in the way of eliminating the *living* content.

Keeping this in view, we have the essential criterion for discriminating the relative merits of different kinds of filters. Other important considerations there are which turn the balance of opinion in favour of one particular kind or another. None, however, can be put on the same level of urgency as the capacity to deal effectively with bacteria. It is to be remarked that in the meantime absolute sterilization is not demanded by the great water authorities. So long as the number of germs carried away by the effluent does not exceed a specified maximum per cm^3., and that *Bacillus coli* is practically eliminated, it is assumed that pathogenic bacilli have been either wholly arrested or so much thinned out that the consumer need have no dread of them. Still, it is plain that the health authorities do not place entire reliance on this assumption. When an epidemic breaks out, they promptly advise the householders to complete the sterilization

* "Water Analysis," p. 113, 10th edition.

of the drinking water by boiling. Hence it is not to be wondered at that the preference of the public tends more and more towards a supply as nearly germ-free as possible. This is why they willingly bear the outlay of bringing water from unpolluted gathering grounds in remote uplands. This also is the reason why a comparatively expensive process of sterilization by ozone has been adopted at many important stations. A wineglassful of water well within the prescribed limit of bacteriological purity may yet contain five to ten thousand germs, so that the consumer may be excused if he questions whether some of these may not be dangerous.

Unfortunately for its reliability, the purification of water differs in an essential point from almost every other mechanical process. Machines and other specific appliances produce a desired result with certainty when the material they operate upon is uniform in form or quality. They are not expected to do the work intended unless this is the case. If they do it at all, they do so imperfectly. But purifying plants have to contend with changes in the raw water, both periodic and unexpected. If mechanical filters are to displace the open sand arrangement, they must be capable of adjustment to varying requirements, and this accommodation should be automatic as far as possible. There are, of course, ways and means of securing a great measure of uniformity in the raw water before it is conducted to the purifying appliances. Thus, for example, the storage of several months' supply in a large reservoir, equalizes the content of sediment, germs, and other offensive matter. Previous treatment over roughing filters is an aid to maintaining an average of impurities to be subsequently eliminated. The same end is sought with the help of sedimentation basins in which coagulants may or may not be applied.

Water undertakers have now a choice of several systems of purification which, it is maintained, surpass the slow sand filter in efficiency and reliability. Some of these have proved notably successful at stations where the older process failed. In making choice of a system, the essential point is the character of the raw water throughout the year. That being determined, the probable efficiency of any system may be judged from its success with waters of a similar type. Storage lightens the duty of the filter-beds, and, if

continued long enough, it is a safeguard against water-borne diseases.

As the available sources of naturally pure water are limited, while the population of cities and manufacturing districts tends to increase, many communities must eventually be dependent on supplies of water which in the crude state are unwholesome. It is well that the general introduction of sewage purification now serves to exclude from rivers the grosser forms of defilement. As the methods of treating sewage become more perfect, and as regulations against the discharge of putrescible matters into streams are more stringently enforced, it may be expected that sentimental objections to the use of purified river water will disappear. Better water for household purposes than that which is to be furnished to Paris from the St. Maur works it would be difficult to imagine. By means of filtration followed by ozonizing, the Marne water will rival that of the springs of Vanne and Dhuys.

The future of water engineering promises a rich and varied crop of interesting problems, the solution of which will become more delicate as the standard of purity is raised. The most significant addition of recent times to the conditions which treated waters must conform to is that which relates to the *B. coli*. It was the great weight attached to the elimination of this germ which chiefly induced the Municipal Council of Paris to sanction the construction of an ozone plant at St. Maur. The close relation which has been established between the art of water purification and the progressive sciences of bacteriology, biochemistry, and hygiene, will in future control, not only expert, but also public opinion, with regard to the degree of purity which drinking water should exhibit.

Among the practical sciences there are few which demand of the student a more varied range of technical knowledge than that of water purification. Hence the need of a properly organized course of training for the water engineer and water manager. A well-defined scheme of instruction would comprise at least as many branches of knowledge, and subjects as scholarly as those which are included in the University curriculum of engineering students. It is to be hoped that the establishment of a faculty of water engineering in technical colleges will not be long delayed.

The large number of sciences which offer contributions to the theory and practice of water purification occasions a difficulty in choosing the best arrangement for a clear exposition of the subject in hand. A study of storage involves the consideration of the animal and vegetable life found in reservoirs, and the vitality of the bacteria present in the crude water. The latter topic claims attention in discussing the care of filtered waters. Sand filtration involves many issues both chemical and biological. The construction of reservoirs and the distribution of the supply call for the application of mechanical principles. There are also subsidiary topics that have risen in importance owing to modern developments in the practice of treating impure water. Among these are the introduction of coagulants, the use of special purifiers, as oxidium and permutit, the application of ozone, the protection of pipes and fittings from corrosion, and the graded mode of successive filtration.

Under the circumstances, it has been found best to follow a natural order of discussion, beginning with the sources of supply, and follow the water on its way to the consumer. The chief divisions into which the subject-matter falls are therefore as follows :

(i.) Sources of supply.
(ii.) Storage and construction of reservoirs.
(iii.) Filtration by sand, including non-submerged filters.
(iv.) Filtration by mechanical filters.
(v.) Purification by ozone.
(vi.) Chemical and biological features of water.
(vii.) Water-softening.
(viii.) Distribution, including plumbo-solvency.

CHAPTER II

SOURCES OF SUPPLY

THE growth of urban communities and the continual extension of water undertakings have greatly limited the available sources of untainted supplies for household use. The practice of replacing dry closets and cesspools by the drainage of sewage into rivers has fouled many sources potentially in reserve. River water which has received considerable quantities of sewage, whether treated or not, is scarcely regarded with favour by communities in quest of wholesome and palatable drinking water. There is, indeed, a well-grounded preference for waters that are clearly exempt from anything more than insignificant defilement with sewage, manure, or any other organic waste.

Among the sources against which no exception is apparently admissible on the score of pollution are deep wells and borings, the upper reaches of rivers and their tributaries beyond the domain of agricultural activity. Lakes fed by mountain streams are in general natural reservoirs of good water. To these must be added the natural drainage of moorlands, uplands, and forests, even when this is chiefly surface water or the outflow from shallow wells.

Deep Wells ; Sources of Pollution.—In the case of deep wells and borings, the purity of the water results from natural filtration, and very often the supply is perfectly free from undesirable germs, and even from organic matter. But there are exceptions. Wells located in the midst of a population are rarely safe. The proximity of cesspools, manure-heaps, and polluted streams, suggests the exercise of caution in all such cases. Dr. Thresh ("Examination of Waters and Water-Supplies," p. 301) instances a number of wells in districts

adjacent to the Metropolis to which surface water, tidal water, and organic impurities, had had more or less free access. There is always the possibility of water percolating to considerable depths by way of fissures and "swallow-holes." If this happens, it escapes the benefit of natural filtration.

Detection of Pollution in Underground Sources.—When an underground source has been found to contain suspicious germs (*B. coli*, etc.), or if the organic content be high, the natural conclusion is that surface matters have access to it through crevices or breaks in the strata. The source of contamination is presumably some cesspool, rubbish-heap, or deposit of farmyard manure in the vicinity, and an inspection of the neighbourhood may indicate one or other of these as the origin. To bring the matter to a test, one must ascertain whether liquids can pass from the suspected place to the well. For this purpose a strong solution of a suitable chemical, as common salt, is introduced at the spot indicated. The well is then pumped continuously, and samples are taken for analysis from time to time. Any decided increase in the amount of chlorine would point to infiltration from the suspected locality.

In place of salt, one may employ lithium sulphate, which is easily detected with the spectroscope, or the dye fluorescein, which has powerful colouring properties. Professor Henry Robinson found that lithia was easily applicable to the investigation of underground sources (Trans. Inst. Mech. Eng., Jan., 1909). Better, however, than any chemical for identifying a source of pollution is an abundant culture of some harmless microbe, as *B. prodigiosus* or *B. violaceus*. For if it be shown that bacteria are able to travel from the spot tested to the well, it is manifest that the process of natural filtration has failed, and that pollution from that quarter may be looked for.

The experiments made at Lake Tegel (p. 73) indicate how a test of the power of underground formations to retain bacteria may be carried out. A chemical analysis would have served no purpose, because the permeability of the strata to liquids was not in question.

Should it have been proved that a solution of salt or lithia has travelled from a rubbish-heap to a well, that circumstance alone does not show that dangerous ingredients would be able

to come in by the same route. On noting the time taken by the test liquid to travel through the intervening strata, and comparing the rate of percolation with that which obtains in unfissured formations, one may be able to infer the actual conditions which exist underground. With compact gravel and unbroken rocks, the rate of percolation vertically is slow, and it is still more so in a lateral direction, probably not more than a few feet per hour. A movement of the test liquid at a speed greatly in excess of this would be a suspicious circumstance, and a confirmatory experiment with a culture of bacteria should then be undertaken.

At the Cambridge County Asylum in 1905, the water from a well in the chalk, 60 feet deep, was suspected of being the occasion of a large number of typhoid cases among the patients. It was shown that the underground supply of the well proceeded in part from the sewage irrigation, distant 1,200 feet, and that coloured liquids could travel that distance in 103 hours through the underlying rocks (Trans. Assoc. of Water Engin., 1907, pp. 108-137).

In considering the circumstances which may influence the content of well waters, it is desirable to take full advantage of the knowledge which is available regarding the geological formations of the district. After studying the disposition of the strata in the neighbourhood of the Cambridge County Asylum, Dr. Thresh concluded that from beyond a certain line the underground water would travel *away* from the well under observation. Experiments with fluorescein proved that this inference was completely justified.

Artesian Wells.—It often happens that underground supplies have to travel from distant gathering grounds. Thus, the waters which find relief in the artesian wells of Paris and London are fed from the outcrop of the porous strata beyond the area covered with impervious clays. In the case of London the chalk formations which are the reservoir of the artesian springs crop out in the Kentish Downs to the south, and in the Chiltern Hills on the north. The quality of the water is nevertheless affected to some extent by the condition under which it is at first absorbed by the porous beds. For though the journey of many miles underground filters out much suspended matter, changes the organic content, and imparts a degree

of hardness, impurities make their appearance in the outflow, at particular seasons. After heavy rainfall following drought, the water of certain deep wells is discoloured, and this is what might be expected if the rock formations are intersected by fissures. Indeed, there can be little doubt that the subterranean stores of water in the chalk beds are here and there fed by swallow-holes, and when they are tapped in the vicinity of these openings the water cannot be of reliable purity.

Yet the strata underlying the London Clay are productive of much excellent drinking water, for it is remarked, in the Sixth Report of the River Pollution Commissioners, that "in the whole course of their experience they had found no catchment basin so rich in springs of the finest drinking water as that of the Thames." A cross-section of the superficial strata from the Chilterns to the Kentish Downs is shown in Fig. 1. The topmost layer of impervious clay is twenty-eight miles broad, and beneath London it has a thickness of 300 feet. Beyond the clay the chalk rocks become the superficial formation, and much of the soil resting on these pervious rocks is under cultivation. The stratum of chalk beneath London is from 600 to 700 feet in thickness, and it is supported by deeper layers of a sandy and porous nature, so that the storage capacity of all these rocks must be very large.*

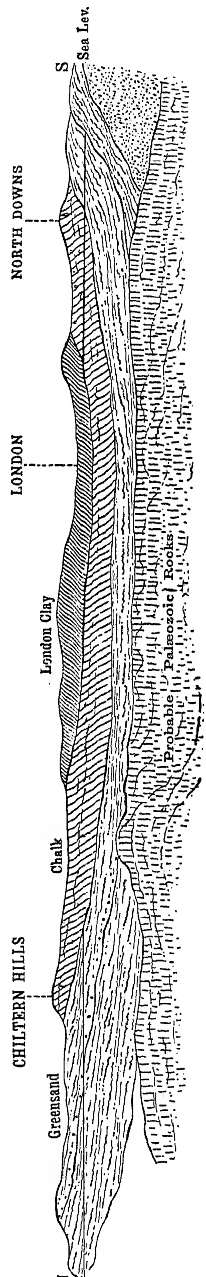


FIG. 1.—GEOLOGICAL SECTION ACROSS THE LONDON BASIN.

Protection of Deep Wells from Pollution.—Precautions against the defilement of deep wells are almost necessarily

* For a full account of the sources from which water-supplies are drawn, see "The Geology of Water-Supply," by H. B. Woodward, F.R.S. (Arnold's Geological Series).

restricted to the immediate neighbourhood of the outflow. The greatest attention should be directed to that quarter from which the underground flow comes to the well. From what direction the well is principally fed may be ascertained by a consideration of the geological formations, and by suitably devised tests with fluorescein. Probable sources of pollution can then be investigated, and measures taken to safeguard the well water. Around the place where the bore is sunk, an area should be enclosed and kept clear of decaying matter. Local circumstances, as the slope of the ground and the permeability of the rocks, will determine the extent of this area, and it ought to extend farther towards the direction from which the underground flow arrives. The bore of the well must be made water-tight to some depth by iron pipes or concrete. At Hastings and at Halstead (Essex) the wells are lined with iron to a depth of 60 feet, and at Leighton Buzzard all water above the 175 feet level is excluded. In the last case the water-tight casing was extended considerably, not on account of any risk from surface water, but in order to avoid the inflow from certain strata containing iron oxide. At Hythe the first 5 feet of the brick lining of the well is backed with cement to keep out surface water. For the next 17 feet the backing is of clay puddle, and the brickwork is carried to 70 feet, and this is followed by iron cylinders to the bottom at 163 feet. The iron casings of the wells belonging to the West Cheshire Water Company are 130 feet deep. Thus, the depth to which the casing of the well requires to be carried must be decided by the existing conditions at each station.

The season in which there is the greatest risk of impurities from the soil reaching the well is that which is marked by heavy rainfall after drought. This occurs frequently in the autumn. The level of the ground water is then quickly raised by the first washings of the superficial layers, which contain organic matter and myriads of bacteria. Wells naturally receive an abundant tribute of the new supplies, seeing that the contour of the water-level underground slopes steeply towards them. At such times the analysis of the outflow should be carefully inspected.

Upland Sources of Supply: Streams and Lakes. — Supplies collected from uplands beyond the limits of cultivation

generally furnish excellent drinking water. The defect most commonly met with is a tendency to act upon lead when the catchment area includes stretches of peaty soil. In that case the influence of organic matter dissolved from the peat is most felt when the storm waters descend. The greater the proportion of spring water as compared with purely surface drainage, the better will be the quality of the service water. This subject is discussed at length in a later chapter. Forest lands, especially those covered with pines and similar species, yield drinking water of high grade. Hence the recommendation has been made by the Local Government Board that lands acquired by water undertakers should be planted. Trouble arises from fallen leaves obstructing the streams and discolouring the water, so that it would appear to be advisable to leave clear margins alongside the water-courses.

Lakes situated in mountainous districts, with feeders drawing from untilled land, are held in high esteem as natural reservoirs of potable water. Many large communities in Britain enjoy supplies of almost ideal purity from the lochs of Wales, of Scotland, and the Cambrian hills. All the advantages of storage accrue to these reservoirs hemmed in by natural barriers. In some cases, as at Loch Katrine and Thirlmere, the original water surface is raised by the erection of a dam, so as to meet the requirements of the installation. The great lakes of North America provide service water for a number of cities, as Chicago, Milwaukee, Cleveland, Erie, and Toronto. It cannot, however, be said that these immense sheets of fresh water now yield faultless drinking water. The supply is unstinted, but the inshores are fouled with sewage, while the great volume of traffic on the lakes contributes to the pollution of the waters. To avoid the grosser impurities, the intakes are carried out by tunnels or submerged pipes reaching from half a mile to a mile or more into the purer deeps. Chicago has lately diverted its sewage from the old convenient dumping-ground on the shore, and carried tunnels four miles out into Lake Michigan, in order to tap the best water that the lake can provide. The inlets of these tubes and tunnels are naturally placed well below the surface to avoid passing ships, floating impurities, and ice in the cold season.

Lowland Sources: Rivers and the Drainage of Cultivated Lands.—Catchment areas which include cultivated lands, rivers in their lower courses, and shallow wells, may be reckoned the principal sources of supply that are clearly open to contamination. Rivers in their lowland reaches are called upon to provide drinking water for vast populations, and, thanks to storage and purification processes, they are not condemned on hygienic grounds. The Thames, the Seine, the Rhine, the Elbe, the Nile, Ganges, and Mississippi, are fountains from which wholesome and palatable waters are prepared by artificial expedients. Water Authorities who draw from rivers may congratulate themselves that the practice of sewage treatment is now becoming general, and in many cases compulsory. Thus is avoided pollution of the worst kind on a large scale. It is manifestly impossible to exclude organic impurities from rivers and their tributaries in traversing cultivated lands, in passing hamlets and farmsteads, in coming within the reach of all kinds of accidental or intentional defilement. But consumers need not be seriously concerned at this, especially if the volume of water flowing is very large compared with that of the foul liquids which it may here and there take in. For the well-aerated river water quickly sets to work on the particles of organic origin, and the living things disseminated in the water join in the attack. In a longer or shorter period the character of the gross impurities is completely altered. The effect is similar to that which occurs when surface water charged with decaying matter filters into the earth. The final steps of the process may not be completed, but they are approached. That is to say, the organic substances tend to become mineralized. If this happens they are innocuous to the consumer. The bacilli of intestinal origin die off in river water. These considerations dispose of sentimental objections to river water in the lower reaches as a source of supply for a community. With storage and scientific modes of filtration, the final result may not be inferior to that which Nature throws up from the stores which she hides underground, and which she constantly replenishes from the surface.

Catchment areas which include buildings and cultivated lands demand careful management and regular supervision. Certain powers have been conferred upon those who undertake to supply communities with water, and, in particular,

some British authorities have embodied in their special Acts a clause enabling them to protect their lands from pollution, and their watercourses from defilement, through the operation of any industry in the vicinity.* It is sound policy for water authorities to become proprietors of their gathering areas, so that they may restrict agricultural operations to grazing, and forbid the use of any manures other than mineral fertilizers. The watercourses should be kept open, cleared of weeds and overhanging vegetation, and the access of the public prevented. All drainage from buildings within the area must be intercepted, and taken by well-laid conduits to a point lower down than the intake. An examination of the watercourses enables the practised eye to discover whether any leakage of foul water is finding an inlet. Sewage and other offensive matters occasion growths of a fungoid nature on the weeds and pebbles, and leave a discoloration of the bed of the stream where they enter, easily noticed when the water runs low. These examinations should be made periodically.

Attention must be paid to the effect of storm water, with special regard to the nature of the suspended matters that may be discharged into the streams from the wash of the adjoining lands. When the ground dips steeply, much of the loose material lying above is swept downwards by heavy rains. It is generally possible in such cases to divert the storm water, or by artificial means to impede the free access of turbid waters descending from slopes. Planting the borders of reservoirs and watercourses has often been advocated, and trees of the pine species are favoured. The planting need not be carried close to the banks.

Where minerals, coal, ironstone, etc., are worked within the catchment area, the drainage of the pits never forms a desirable addition to the supply. Deep workings exhaust the underground waters that might otherwise contribute to the general intake. Nevertheless, it is better to divert the discharge from the pumps. It is not only fouled by the workers, but it generally is charged with iron and other ingredients of the seams and veins with which it has been in contact.

* The clause is to the effect that "they may hold any lands or servitudes which they may deem necessary for the purpose of preventing the fouling of any water which they are authorized to take, and for the protection of their waterworks against nuisances."

Lands acquired for Gathering Grounds.—The following water authorities have acquired land within their gathering areas for the purpose of preventing pollution :

ENGLAND	Birmingham	45,562 acres.
	Bolton	2,356 ,,
	Bradford	9,000 ,,
	Liverpool	23,000 ,,
	Leeds	15,000 ,,
	Manchester	11,000 ,,
	Newcastle	6,600 ,,
	Oldham	2,000 ,,
IRELAND.—	Belfast	13,322 ,,

SCOTLAND. — *Edinburgh and District Water Trust* have purchased about 6,000 acres, or nearly the whole of the area draining to the Talla Reservoir.

Glasgow has acquired the feuing rights of the lands draining into Loch Katrine.

Lanarkshire Middle Ward District Committee have specially arranged to keep certain fields out of cultivation near their reservoirs.

At *Paisley* the Water Engineer, Mr. Lee, states that the drainage area at the old works of the Corporation extended to about 900 acres, and that 600 acres have already been bought. The land is let for the grazing of cattle and sheep, and no town manure is allowed for top dressing.

Kirkcaldy and Dysart.—(*a*) The Water Commissioners have purchased two estates in the vicinity of their waterworks, with the object of having full control of them, so as to be able to prevent pollution of the streams feeding their reservoirs, and these estates are let, but in fields where there is access to the watercourses sheep-grazing only is permitted. The total area of the gathering ground is 3,900 acres, and the rental derived from the leases with the restrictions mentioned represents 4 per cent. of the purchase price, which was at the rate of £160 per acre.

Filtration of River Water into Adjacent Wells. — Instead of drawing water directly from a river, it is now not an uncommon practice to sap the moist strata adjoining by means of deep trenches parallel to the banks. Advantage is thus

taken of a natural filtration, and if the deposits which bound the course of the stream are gravelly or sandy, an abundance of water is secured, much superior in quality to that in the open river.

Dangers of Contamination ; Localities supplied from Underground Sources.—In an article upon water purification by natural filtration (*Centralbl. f. Allg. Gesundheitspflege*, 1908, H. 9, 10), Professor W. Prausnitz refers to the large number of important towns which are supplied from underground sources. The water is frequently drawn from the immediate neighbourhood of a river, and is obtained either from wells and boreholes, or from galleries excavated parallel to its banks. A wide range of analytical researches has proved that these sources are very liable to admixture with imperfectly filtered, or even raw, water during times of flood. The proportion of impure water which then finds access to the supply depends on local factors, such as the nature of the strata, the distance from the flooded stream, and the extent and depth of the inundation. Prausnitz gives instances in which the content of bacteria increased by thousands per cm^3. This is confirmed by Professor Kruse (*Zeitschr. f. Hyg. u. Infektionskh.*, 1908, Bd. 59, pp. 6-94), who, however, is not certain that epidemics have been caused by this form of contamination. He suggests a number of remedies, as the intercepting of flood water by dams and barrages, the fortifying of the adjacent banks with clay and turf, raising the level of the surrounding land, and the rejection of doubtful water as occasion arises. On the whole Dr. Kruse is inclined to favour natural filtration, especially as there is little risk of the bed of the stream becoming choked up with algæ or other growths, and so preventing the water from percolating. The current obviates this inconvenience, so characteristic of artificial filter-beds. From time to time, also, floods sweep away all slimy matters. It is not without significance that, when the bed of the river has been scoured in this way, there is observed a marked increase of bacteria in the neighbouring wells, and Dr. Prausnitz concludes that part of the increase may be due to direct percolation from the river-bed. The permeability to bacteria of the intervening space between river and well must depend on the nature of the ground.

In Dresden, after the service water had been rendered less

pure in consequence of floods, Dr. Meinert recorded a far higher mortality from diarrhœa among young children, and a large increase of stomach catarrh among adults. Dr. Prausnitz confirms the appearance of diseases of this nature, concurrently with heavy flooding at various localities. He strongly advocates daily chemical and bacteriological analyses during periods of danger. Also the temperature of the output from deep wells should be noted, for any sudden alteration is probably traceable to the admixture with surface water.

Natural filtration plays a part in the preparation of water for the use of the city of Amsterdam. The collecting ground consists of many acres of sand-dunes, the property of the water undertakers. The land is a barren, undulating waste which has been canalized and drained by a network of deep channels. Rain water percolates downwards through the sand, picking up on the way very considerable quantities of mineral matter, so that on reaching the works at Leiduin it holds about 36 grains per gallon, largely salts of lime. It also dissolves iron in its passage towards the canals, and this requires a special treatment for its elimination.

The bacterial population is considerable, averaging about 2,000 per cm^3., so that the raw water stands in need of thorough filtration.

Water of better quality is obtained for the supply of Brussels from galleries driven underground among sandy strata in the direction of the Forest of Soignes. The main conduit is fed by galleries driven sideways, so as to pick up as much as possible of the rain which is absorbed by the sand. In order to husband excess water during heavy floods, portions of the walls of the underground passages are made water-tight at selected spots. The well-soaked strata are thus forced to retain their charge until the adjoining beds draw it away as the ground water level sinks. These concrete-lined portions of the galleries, or "serrements," as they are called, thus provide an ingeniously cheap method of storage.

The town of Gratz in Austria receives its water from wells sunk in alluvial sand alongside the River Mur. Flooding occurred in May, 1907, and immediately there appeared in the town a marked increase of cases of stomach and bowel complaints. The alluvial bed is 30 feet deep, resting on an impervious clay. Investigations proved that the supply water was

very much polluted while the floods lasted. In response to a public outcry, new wells have been constructed at a distance of 120 yards from the Mur. These have yielded good drinking water. The old works now serve as a stand-by to be used in dry weather. Much care has been taken to make the linings of the wells water-tight.

Stuttgart meantime (1910) stands in pressing need of an increased reserve of drinking water, seeing that the filtered Nutz river water is strongly objected to by the towns-people on account of its bad odour. There is a moderate supply of spring water which was considered sufficient for the consumers forty years ago, and which at the present day would furnish a few gallons per head. Numerous localities, some near, some very distant, have been explored with a view to resolving the problem before the city authorities. It has been proved that the sand and gravel beds lying close to the River Neckar, though only 10 or 12 feet deep, effect a complete purification of the river water, which percolates under ordinary circumstances. But whenever the river comes down in flood, the whole of the ground water in these river gravels is turbid and laden with germs. Hence the project of augmenting the supply from this source does not meet with great favour, and it is likely that the choice will fall on the River Enz, forty miles distant, in the Black Forest.

During the past year researches have been in progress near the town of Landeshut in Silesia. By one scheme it is proposed to tap the alluvial beds in the Bobertal, close to the River Bober. Numerous borings from 12 to 60 feet in depth have been put down, and in general the water found is of good quality. In permeating through the gravels, the soft river water adds three or four degrees (German standard) to its hardness, and in hot weather its temperature experiences a welcome lowering of 5° to 6° Cent.*

The city of Worms was provided with a roughly filtered service of Rhine water in 1888. The arrangement was as follows : An iron cylinder 10 feet in diameter, with perforated wall, was sunk to a depth of 3 feet below the bed of the river. Within this was set a large perforated cone connected with a 16-inch service main. The remaining space between cone and cylinder was packed with rough gravel. The result, as

* See *Gasbeleuchtung und Wasserversorgung*, October, 1909.

might be expected, was never satisfactory, and after the town of Mannheim began to pour sewage into the Rhine the water was quite dangerous. A new supply has now been obtained from boreholes in the Bürstädter Forest, eight miles distant. This is of fine quality, but it contains much bicarbonate of iron in solution, and this has to be dealt with by aeration and filtration. At the same time traces of sulphuretted hydrogen are oxidized.

Conditions very similar to the above may be noted in con nection with the water-supply of Bingen. Formerly the towr obtained its water-supply from two wells, one 50 yards, the other 60 yards, from the Rhine. The wells were built in to some depth, but the bottom portions were left with the natural walls. The water obtained was found to be fairly good as a rule, unsatisfactory only at times. Hence a new and better supply has been requisitioned from underground sources five miles distant. The site was selected by an eminent geological expert. Berlin now draws its domestic supply from deep borings near the shores of Lakes Tegel and Müggel (see p. 73).

Contamination of spring water with sewage gave rise to a serious outbreak of enteric fever in a small market-town of Southern Austria; 386 of the inhabitants out of 1,700 were struck down (*Centralbl. f. Allgem. Gesundheitspflege*, 1908, H. 9 and 10, M. Kaiser). The foul water percolated through the ground for some distance without losing its dangerous germs. After the cause had been discovered and remedied, the whole installation was disinfected with lime, 300 grains per gallon being applied for a time. The bacteria, which numbered on the average 310 per cm^3., were thus destroyed.

Following upon the closing of the Stralauer Waterworks at Berlin, which gave unsatisfactory drinking water, the mortality from bowel diseases decreased from an average of several hundreds in the preceding twelve years to the present figure of 64 per annum.

The town of Bedford (England) derives its water from wells sunk near the banks of the Ouse. It is realized that pollution is not excluded by the percolation from the river, and accordingly the water is treated carefully at the works, being first passed through Candy filters, and then sprinkled over non-submerged sand-beds. Some part of the effluent from the

mechanical filters goes to sand-beds of the old type. The service water is remarkably pure.

A very large amount of water is pumped within the area administered by the Kent Water Company along the lower reaches of the Thames. It is mostly used for industrial purposes, and Mr. Clayton Beadle (see his paper read to the Royal Society of Arts, reproduced in *Water*, vol. x.) judges it to be pretty near the raw Thames water in its general characters.

On the other hand, the Kent and Lea valley wells, which contribute to the Metropolitan supply, yield very good water from the standpoint of chemical analysis, and over 90 per cent. of the samples tested bacteriologically showed no *B. coli* in 100 cm^3. (Fourth Report Metrop. Water Board, 1910).

Water of good quality is obtained from wells sunk in the alluvial sands alongside the bed of the Mississippi.

The city of Nashville, Tennessee, obtains water from a filtration gallery which taps the underground waters by the Cumberland River. Peoria, Illinois, draws from gravel deposits left by the River Illinois. In India, the town of Trichinopoly is supplied from a number of wells sunk 25 feet below the bed of the River Cauvery. Here a constant flow of water is pumped, notwithstanding the fact that the Cauvery is dry for five months of the year. In South Africa the population of the Rand are dependent on deep wells, which provide satisfactory water for domestic use. On the other hand, the alluvial deposits in Lower Egypt do not yield good water, owing to the richness of the Nile Delta in organic matter.

Shallow Wells.—Many small communities, agricultural holdings, and private dwellings, depend upon shallow wells which are fed by surface water purified to some extent by percolation through the superficial strata. These are much exposed to contamination, and are undoubtedly responsible for many of the outbreaks of epidemic disease in country districts. As it is in general impossible to dispense with this method of obtaining a domestic supply in thinly-populated districts, it is all the more necessary to adopt every reasonable safeguard against pollution. County authorities in Britain now have powers of examining the sources of drinking water, and of enforcing compliance with the conditions laid down by

their Medical Officers and Sanitary Inspectors. The most obvious of the measures that should be taken to guard the well from the easy access of pollution may be stated as follows :

1. The well should be removed as far away as possible from manure-pits, cesspools, and other possible sources of contamination, and always towards the direction from which the underground waters flow. It should not be situated in a hollow to which surface water tends, but rather on a site which naturally throws off the rainfall. Nor should it be placed on ground which is liable to be inundated with flood water.

2. A space all round should be fenced in, and kept under grass or planted. Local considerations may limit the radius of this space to a few yards, but it is doubtful whether anything less than 100 feet can be looked upon as a real safeguard in gravelly strata. The enclosure should extend more in the direction from which the subsoil water percolates.

3. The well should be cased water-tight to the bottom, or in any case to not less than 20 feet. The casing should be carried 2 or 3 feet above the surface, and the ground surrounding should be laid with cement or otherwise made water-tight to a distance of 6 feet. It is recommended that the pump be separated from the well-head, and placed some distance away, so as to minimize risks from spilt water finding its way inside. The top of the well should be protected from dust by a suitable covering.

4. Samples of the water should be taken for analysis from time to time. In addition the consumer should observe the character of the supply, noting how it changes with weather and season. Wells which become turbid after heavy rainfall are always to be suspected.

Surface Springs.—Springs other than artesian wells are generally called "surface springs," because they are derived from the water gathered by superficial beds of porous rock. The water issues from the ground at the junction of the permeable bed with one that is less pervious.* The quality of the outflow depends on the nature of the strata through which it has permeated, the depth of the natural layer of filtering matter, and the presence or absence of sources of contamination at the

* See "The Geology of Water Supply" (H. B. Woodward), chap. vi.

surface, particularly in the vicinity of the spring. If cultivated lands are near by, the annual manuring replenishes the surface with organic matter. All farmsteadings and dwellings on the gathering area are possible sources of contamination. Springs that formerly gave serviceable supplies have been abandoned owing to the increase of population on the area which receives the rainfall, that eventually issues at the surface. Such has been the case with the Bagshot springs that furnished London with water for many centuries.

Some of the cautions which have been stated as bearing on the use of shallow wells would apply to surface springs. It is almost unnecessary to say that the outlet of the spring should not be lower than the site of the dwelling-houses in the vicinity A space around the spring ought to be reserved, and surface water excluded by appropriate constructions. It is not to be expected that the use of farmyard manure can be controlled to any great extent, but at least in the neighbourhood of the spring mineral fertilizers ought to be substituted. Periodical analyses of the water should be made.

Rain Water.—At not a few homesteads in Britain, the best water available for domestic use is that which is collected from the roofs of the buildings. Rain water is carefully collected in many countries where it is difficult to obtain water from the ground. Rain water is soft and insipid to the taste. Its purity is hardly open to question except in the vicinity of towns. It acts very freely on lead, and cannot be stored in cisterns made of that metal. The first runnings from the roofs are of course rejected. The conduits must be kept clean, and the cistern covered to prevent the growth of algæ. With respect to domestic supplies from shallow wells and surface springs, it should not be forgotten that, wherever there is any question about the purity of the drinking water, all danger may be avoided by the use of one or other of the excellent household filters now obtainable at a moderate cost. Careful attention must, of course, be given to the cleansing of domestic filters, especially charcoal filters, from time to time, otherwise they cease to yield pure water.

CHAPTER III

STORAGE

THAT storage exercises a wholesome influence upon impounded water in the way of removing sediment is patent to all. But that other important and far-reaching processes come into play during storage is a circumstance which has been brought to our knowledge by modern investigation and research. Dealing with micro-organisms in impure water, Frankland (in 1892) called attention to the rapid extinction of bacteria in streams and ponds. Following this, it was generally accepted by epidemiologists that the germs of typhoid and other infectious diseases become extinct within a few days after they are carried into watercourses. In 1903, Professors Jordan, Russell, and Zeit, conducted experiments to determine the longevity of the typhoid bacillus in natural waters (*Journal of Infectious Diseases,* vol. i., pp. 641-689, 1904).

Working with Lake Michigan water and Chicago River water, Zeit found that in the former case extinction of the bacillus took place in eight days at latest, while in the river no vitality could be detected after three days. His method of experimenting was one that sought to imitate natural conditions as closely as might be. The disease germs were added to measured volumes of water enclosed in collodion or parchment sacs, which were then immersed in the lake or river, thus giving free scope to diffusion.

Professor Jordan made similar experiments at the Chicago Drainage Canal, which carries a large volume of sewage. He confirmed the disappearance of the living typhoid bacillus from his sacs after two days in almost every instance. However, it does not appear that he tested a volume larger than 1 cm^3. in making his cultures; otherwise he might have obtained indications of the bacillus after a greater lapse of time. On the

other hand, Zeit confirmed his results by searching much larger volumes as soon as the smaller quantity failed to give indications.

The vitality of the typhoid germ in river water is a subject of the utmost importance in relation to the disposal of sewage. and numerous investigations have of late been set on foot, The inferences arrived at vary with the conditions, as might have been anticipated, but there appears to be a general agreement that 99 per cent. of the typhoid bacilli introduced into a natural water perish within a week's time.

London Stored Water: Dr. Houston's Researches.—So far as concerns the Metropolitan water-supply, this matter has now been thoroughly investigated by Dr. Houston, who has made the most important and conclusive research that has yet been undertaken (First Report on Research Work, 1908). Samples of raw water from the Thames, the Lea, and the New River, were inoculated with the typhoid bacillus to a given number per cm^3., and the sample bottles were stoppered and set aside in a dark place. They were tested at the end of one, two, three weeks, and so on, successively, till no result could be obtained from a volume equal to 100 cm^3. ($3\frac{1}{2}$ ounces.) Dr. Houston found that 99·9 per cent. of the bacilli had ceased to possess any power of multiplication after one week. Of the survivors, and these may be regarded as endowed with a special measure of longevity, from 80 to 99 per cent., perished by the end of a second week. Those that survived after this time can only be looked upon as stragglers, seeing that they represent but 1 or 2 out of 100,000 in the highest count, and on the average about 1 per 1,000,000. In no case was any trace of the bacillus found after eight weeks. The following are the precise figures of one experiment:

Typhoid bacillus introduced ..	475,000 per cm^3.
One week after	80 ,,
Two weeks after	11 ,,
Three weeks after	2 ,,
Four and five weeks after	Trace found after careful isolation.
Six weeks after	Not found in less than 10 cm^3.
Seven weeks after	Not found in less than 100 cm^3.
Eight weeks after	Absent from 100 cm^3.

The lesson which these figures convey cannot be misapprehended. It is very lucidly exhibited by Dr. Houston in

its practical aspect, when he points to the "safety change" which comes over river water under storage. Pathogenic germs are very nearly eliminated in three weeks. Impounded for that period, a raw water which is in a dangerous state goes far to complete a process of regeneration. Any temporary defect in the subsequent filtration can hardly now be a source of danger to the consumers. Even without the purifying effect of the filters it could hardly convey disease. It has reached the safety condition.

During three weeks' storage the sum total of all the microbes in river water, or in water contaminated from any source, diminishes at a rapid pace. Dr. Houston found that 220 germs in a sample of New River water fell away to 48, 620 in Lea water to 106, 450 in Thames water to 53, by the end of the third week. Perhaps more remarkable was the fact that, out of the bacilli that would grow on a special medium selective of excremental (and therefore suspicious) germs, not 1 in 10 of the average persisted for three weeks in stored water.

Satisfactory as is the knowledge now brought to hand by these investigations at the Metropolitan Laboratory, it has, of course, to be borne in mind that total extinction of the typhoid germ, under laboratory conditions of experiment, must be reckoned on the basis of several weeks. It further appears that certain types capable of growing at blood-heat on an agar medium with bile and lactose (excremental bacteria) do not perish even after two months. Therefore, while storage is an admirable preparation for the treatment by filters, it should be regarded as a preliminary to, rather than as a substitute for, that process. After adequate storage, filtration may well be looked to, in order to deal the finishing blow upon the straggling survivors of disease germs, if such really occur.

Dr. Rideal's Tests with River Dee Water.—In the course of his evidence before the House of Lords in regard to the Aberdeen Water Bill (1910), Dr. Rideal stated that he had infected samples of Dee water with a culture of typhoid bacilli to the extent of 15 per cm^3., and that a storage of eight days was sufficient to cause their disappearance, so far as could be judged when 10 cm^3. was examined. From his examination of the water of the Dee, which is a stream comparatively pure as compared with the Thames, he had come to the conclusion that, on being

stored for ten days, the water would be so much improved that, with the subsequent purification by sand filtration, it would be entirely innocuous to the consumers.

It is to be noted that Dr. Rideal's tests of Dee water were on a less comprehensive scale than those carried out in the laboratories of the Metropolitan Water Board. From his evidence it did not appear that he had examined larger volumes of the infected water than 10 cm^3., otherwise it might reasonably have been expected that the disappearance of the bacillus would have been indicated after three or four weeks.

Pathogenic Bacteria: Importance of Isolating these in the Bacteriological Analysis.—In considering the bacteriological analysis of a water, and the inferences to be drawn therefrom, it has to be kept in view that the detection of "specifically" pathogenic bacteria is attended with very considerable difficulties, and that consequently the recommendation has been made that search should be directed to find the ordinary excremental bacteria (*B. coli*). In any case it is desirable that an estimate of the latter should be made, in order that a rational conclusion may be come to regarding the degree of sewage pollution. The waters of the Thames and Lea nearly always indicate the presence of *B. coli* in 1 cm^3. Frequently it is present in 0·1 cm^3. and even in 0·01 cm^3.

In neither of these two streams, nor in the New River, did Dr. Houston succeed in isolating the typhoid bacillus, although a most extensive and very carefully executed research was conducted by himself and the laboratory staff (see Dr. Houston's Second Research Report, 1907-08). Needless to say, the most recent and most reliable tests for the typhoid bacillus were applied, and the experiments were continued for twelve months. Two hundred and ninety-four experiments were made with waters drawn from the Thames, the Lea, and the New River, and on each occasion 100 cm^3. was the measure used for the search. In the total volume submitted to culture there were many millions of bacteria of all sorts, and of these some 7,000 that *might* possibly have been typhoid, seeing that their growth up to a certain point conformed to that of typhoid, were specially dealt with. Not a single *B. typhosus* could be isolated. Clearly this was a thoroughgoing investigation, and one which should be gratifying to consumers within the Metro-

politan area. Yet Dr. Houston does not for a moment advise any slackening in the purification of the raw waters from the sources mentioned. All of them are subject to sewage pollution, and no one can predict the moment at which one or other of these streams might begin to disseminate epidemic germs.

Thames and Lea Waters proved to contain very Few, if Any, Pathogenic Bacilli.—More recently Dr. Houston has confirmed the results which were published in his earlier reports. By following the most stringent conditions of analytical work, he has reduced the possibility of error in his deductions to a minimum, and he has established his former conclusions beyond the range of doubt (Fifth Research Report, 1910).

The method adopted was that to be described in connection with the vitality of the cholera vibrio. Each sample of river water was divided into two equal portions, and one half infected with a definite number of typhoid bacilli (2·3 per cm^3.) and also with Gärtner's bacilli (0·7 per cm^3.). The other half of each sample, which had not been infected, was subjected to exactly the same analytical treatment as that to which these pathogenic bacteria had been added.

It is plainly to be deduced from the series of experiments that it is possible to detect a single *B. typhosus* in 6 cm^3., and one Gärtner's in 14 cm^3. And as it was not found possible* to isolate either of these bacilli from the non-infected water, the inference is that there are at all events fewer typhoid bacilli in the crude Thames and Lea waters than one in 6 cm^3., and fewer Gärtner's bacilli (*B. enteritidis*) than one in 14 cm^3. (Fourth Annual Report, 1910, p. 7).

The danger of epidemic diseases emanating from the chief Metropolitan sources of supply, if it exists at all, must be very remote, especially when adequate storage and careful filtration are interposed between the reception of the water and the delivery of it to the consumers.

B. Coli Test: Disappearance of the Germ in Stored Water.—The importance of testing for *B. coli* as being a typical microbe in sewage-polluted waters has already been referred to, and it is very germane to the subject of impounding

* From the large volume of non-infected water which was put to the test, there were isolated one typhoid-like bacillus and one indistinguishable from Gärtner's.

water to discover how far this species is eliminated during a period of comparative quiescence. Dr. Houston has settled the question so far as the waters stored by the Metropolitan Board are concerned, and in his Third Research Report he conclusively shows that enormous advantage accrues from storage. Experiments were made weekly, and often bi-weekly, during the course of a whole year upon Thames and Lea raw and stored waters. The general results as summarized by Dr. Houston are remarkable. Fifty per cent. of the samples of *crude* Thames water contained typical *B. coli* in $\frac{1}{10}$ cm^3., but of the *stored* waters at Staines, Chelsea, and Lambeth, 27 per cent. contained no typical *B. coli* in samples 1,000 times larger —*i.e.*, in 100 cm^3. Of all the tests made with Staines and Chelsea stored water, only 33 per cent. could be got to give indications of the bacillus in question with a quantity so small as 10 cm^3. The Lambeth reservoir did not quite approach this high standard, typical *B. coli* having been found in 1 cm^3. of a goodly number of samples during December to February. But on the whole the stored water is, with reference to typical *B. coli*, from a hundred to one thousand times better than the raw water.

Theoretically the water is stored for about fifteen days at Chelsea and Lambeth, and for ninety-five days at Staines; but it can easily be understood that the water which is brought to the filter-beds may have been impounded for very different periods, according to the exigencies of supply and demand.

Turning now to Lea water, Dr. Houston found results even more satisfactory than those above quoted. In *raw* Lea water *B. coli* is about as frequent as in the Thames. Sixty-seven per cent. of all the *stored* samples yielded no result at all with 100 cm^3. Only one sample out of a hundred gave the indication sought for with 1 cm^3., and four only with 10 cm^3. In fact, there were fewer typical *B. coli* in 1,000 cm^3. of stored water than in 1 cm^3. of raw Lea water. The nominal period of storage here is fifty-eight days. With the reduction of the number of *B. coli* we are chiefly concerned at this point, but it may be mentioned in passing that by storage of Lea water there resulted a reduction to the extent of 97 per cent. of all the bacteria capable of growing on a culture medium at blood-heat, and of those that, being chiefly excremental microbes, could germinate on a bile-salt medium.

The *Bacillus enteritidis sporogenes* was also sought for, and, dealing always with 10 cm³. of raw or stored water, this microbe was found in 36 per cent. of Thames water samples, and in about 12 per cent. of the same water impounded. It also occurs in 36 per cent. of the Lea River samples, but it actually could not be detected in the Lea stored water at all, an eminently satisfactory result.* The storing of Lea water brings yet another advantage which Dr. Houston has discovered. He has frequently noted in his reports the distinction between typical and non-typical *B. coli*, the former giving, *inter alia*, the "indol reaction." The discovery mentioned brings into relief the circumstance that typical *B. coli* die faster in the Lea reservoirs than do the non-typical, which are regarded as being less objectionable. Out of every 100 *coli*-like microbes in raw Lea water, 85 per cent. are typical. Out of 100 *coli*-like microbes in the stored water, 63 per cent. only were typical. We remember that the volume of stored water containing 100 *coli*-like microbes would be about one thousand times greater than that of the raw water holding an equal number. In regard to this point, it may be added that the improvement is not so well marked in the case of Thames stored water, but there is a slight degree of betterment.

We can no longer doubt that storage for a sufficient time is capable of eliminating to a very large extent the undesirable flora of sewage.

Stored Water; Comparative Results in a Scotch Case.—As bearing on these conclusions with regard to the storage of river water, the following facts relating to the storage of water gathered from an area in the South of Scotland, partly cultivated, are of special interest. There are several small feeders of the main stream leading into the reservoir which provides storage for over 250 days. The average number of colonies of bacteria per cm³. in the stored water at its outflow was 300. Of these, about half a dozen were able to grow in McConkey bile-salt medium at blood-heat, and *B. coli* was not discoverable in 50 cm³.

On the other hand, the water entering the reservoir, and consisting of the united flow of five or six contributory streams was very much inferior, bacteriologically speaking. The average

* Third Research Report, p. 8, and Third Annual Report, Table E.

number of colonies of all kinds was 1,200 per cm^3., and of these about 30 flourished at blood-heat on the special medium. *B. coli* could be detected in 0·5 cm^3. This water was distinctly below the ordinary standard of purity. The reservoir water, on the other hand, might be regarded as potable. Among the feeders of the main stream, one at least was grossly polluted.* It is not a large contributor, only delivering 2,000 gallons per hour, but the intermingled sewage raised the number of excremental bacteria to many thousands per cm^3. This very objectionable tributary polluted the water in the main stream appreciably for a considerable distance below its entrance. Samples drawn near this point showed results far inferior to those obtained lower down. The number of bacteria of all kinds there rose to 3,000 per cm^3., and of these 400 were clearly excremental, with *B. coli* strongly in evidence. Flowing in a channel one and a half miles long, and receiving a considerable admixture of other waters, the main streams arrived at the reservoir in the condition above stated.

The analysis shows that the stored water is greatly improved as regards the bacterial content, and of course also in the matter of turbidity. Table I. gives the average results:

TABLE I.

	Parts per 100,000.					Bacteria growing at—	
	Total Solids.	Oxidized Nitrogen.	Free Ammonia.	Albuminoid Ammonia.	Oxygen consumed.	20° C.	37° C.
Raw water ..	24	37	0·007	0·026	0·19	1,100	113
Stored water ..	12	24	0·002	0·020	0·20	270	7

B. COLI TESTS.

Raw water	present in 0·5 to 1 cm^3.
Stored water	not found in 50 cm^3.

Effect of Storage of River Water in the Dark on B. Coli.—When crude Thames or Lea water is kept in a stoppered bottle in the dark, the *B. coli* perish so rapidly that after a week it is generally impossible to isolate them from 1 cm^3. Taking 10 cm^3., the average life under the above conditions is eleven days, but occasionally they were detected after three

* All objectionable tributaries have now been excluded from this particular supply.

or four weeks. The *B. coli* persists for a shorter time than the general flora of bacteria, so that while in raw Lea water there is (roughly speaking) one typical *B. coli* to every 1,000 of all sorts, in the stored water there is but 1 in every 10,000.

Of course, these ratios are struck from a large number of analyses, giving here and there results widely different from the average. But there is no uncertainty about the principle stated, for Dr. Houston shows that the ten *worst* samples of Lea stored water were superior to his ten best samples of Lea raw water, so far as *coli*-like forms were concerned.

As a general deduction from considerations of the vitality of different species of microbes, and from the results of extensive tests upon the wholesome influence of storage, it may be said that, if a purification process succeeds in destroying *B. coli*, it will *a fortiori* eliminate the more delicate microbes of typhoid and cholera. This view is accepted by eminent authorities, and, in particular, at the Paris Waterworks it is now considered a necessary and also a sufficient mark of efficient filtration that *B. coli* should not be present in the effluent.

Vitality of the Cholera Vibrio in River Water.—The appearance of cholera from time to time in the Western Hemisphere, its rapid spread when once it has made good its footing, and the deadly character of the malady, have led to exhaustive researches in many countries regarding the manner in which infection is conveyed. The important discovery, due to Koch, of the cholera vibrio defined more clearly the field of these investigations. It remained to find out precisely in what media the vibrio might occur, its vitality in these, and how far any one of them might serve as a carrier of the bacillus to human beings.

It is generally accepted by bacteriologists who have studied this question in connection with outbreaks of cholera in India, Russia, and Germany, that the disease is quite capable of being conveyed by water-supplies, and that infected water is presumptively responsible when a wide area is attacked.

Dr. Houston has recently turned his attention to the vitality of the cholera vibrio in Thames, Lea, and New River water, and he finds that there is no difficulty, deserving to be called insuperable, of recapturing, as it were, by aid of his culture media,

specimens of the vibrio which have been previously disseminated in the samples of river water. Yet there are difficulties, the chief one which confronts the bacteriologist being that the true cholera vibrio is imitated by other vibrios, at present reckoned harmless, not only in microscopic appearance, but also in their behaviour under the delicate reactions by which the Koch bacillus is identified.

The precautions which Dr. Houston took care to adopt would seem to leave nothing to be desired from a scientific point of view. Taking a definite volume (1 litre) of river water, he divided it into two equal parts, infected one half with a small dose of true cholera vibrios, added some peptone to encourage growth, and, after incubating for eight hours at 37° C., plated a number of samples from each portion, and proceeded with the subculture of these. He repeated this experiment on twenty-three occasions during a period of four months, and made in all 1,050 subcultures of each of the two kinds of water, infected and non-infected.

Dealing first with the subcultures of non-infected water, none satisfied the tests for the cholera vibrio. The raw water, therefore, while containing many bacteria of different species, contained none possessing the characteristics of the true vibrio. There was nothing, therefore, in the raw water that could give rise to a doubt regarding the reliability of the tests if they were satisfied by the contents of the infected portions.

Coming, then, to these latter, the subcultures were put to the proof, and sixteen out of the twenty-three samples gave the proper reactions. Of the seven that did not respond to the tests, six had received very feeble doses of the cholera vibrio—namely, from 1 bacillus in 30 cm^3. to 1 in 3 cm^3. In the seventh sample the infection was about 3 per cm^3.

All the sixteen samples which gave positive indications had received very sparing doses of the vibrio, in order that it might be distinctly shown whether a very few germs of this species scattered through the water could be isolated and identified. Hence the maximum number of vibrios introduced only once exceeded ·5 per cm^3., and was in general only 1 or 2. In five instances it was much less than 1 per cm^3.

Effect of Storage on the Germs of Cholera.—It being, therefore, clear that scientific method can track out the germs of

cholera three times in four when their number is sparse and near the vanishing point, we can turn with interest to Dr. Houston's experiments regarding the vitality of the germ in river water. He was able to prove that, with an artificial infection of millions per cm^3., the very longest time that their presence could be detected in so large a quantity as 100 cm^3. was less than three weeks. Further, the storage of the infected water for one week brought about an enormous reduction in the number of germs. On the average, only 1 in 1,000 survived for that short period. In two weeks the vibrios could hardly be isolated from 10 cm^3., and by the end of three weeks no trace of infection could be detected when 100 cm^3. was tested. These notable experiments confirm the conclusions which had been already arrived at respecting the great advantages which accrue from storage. The cholera vibrio is much less persistent than the bacillus of typhoid. One may conclude that, even in the very improbable event of London water becoming polluted with cholera germs, the water would be rendered sterile, so far as these were concerned, by a month's storage. In his report, Dr. Houston replies to some possible objections that might be suggested against a strictly literal interpretation of his bacteriological results. For example, it is supposable that the vibrios imported into river water alter their vital character on account of the environment, and so fail to react in the same way as those which are taken directly from a patient. It is hardly within the power of the bacteriologist either to prove or to disprove that vibrios disseminated in water undergo a metamorphosis of the nature suggested. If such really occur, one would have anticipated that, as the samples were subcultured from week to week, there would have been observed a progressive reluctance on the part of the colonies recovered to yield the typical reactions. This, however, was not so. Dr. Houston kept a mixed strain of vibrios alive in sterilized water for four weeks, and obtained the indications looked for in the subcultures all that time. One week later the vibrios were extinct, for no growth of any kind appeared on the plates.

It may be said that the isolation of a few vibrios from river water containing numbers of bacteria of other descriptions is attended with difficulties. We may admit this, and still look with confidence on Dr. Houston's results, seeing that they are

based on an ample array of experiments. As many as 100 to 180 subcultures were made of the various samples.

It is worthy of notice that bacteriologists favour the opinion that pathogenic bacteria are more persistent in natural waters during cold weather. This may well be due to the fact that in winter the action of the sun's rays is neither so powerful nor so prolonged as in the warmer season. Further, during warm weather, the saprophytic bacteria, by their active growth, may decimate or even suppress entirely the pathogenic microbes.

The history of cholera epidemics contains no more striking illustration of the evil consequences of infected waters than the sombre record of the ravages of this disease in Russia since its appearance in 1907. The presence of the malady was first notified from Samara, a large town standing at the most easterly bend of the Volga, and at the junction of lines of railway branching eastwards. Whether owing to infection conveyed by the river, or by the extensive traffic over its waters, cholera very soon appeared at towns on its banks as far down as Astrakhan at its mouth, over 600 miles to the south. Not only were the lower reaches of the stream invaded, but towns a long way up the river fell under the scourge. Numerous cases occurred at Nijni-Novgorod, which lies 400 miles upstream, nor did the march of the epidemic slacken till it reached the province of Yaroslav, 200 miles beyond. In short, the whole course of the river for 1,200 miles was thickly marked with cholera-stricken towns and villages within a brief period after its notification at Samara in the month of July. By the end of the year many thousands of the inhabitants had been seized with the malady, and one half of the cases terminated fatally.

From the infected spots alongside the great river the disease spread rapidly, crossing into the Valleys of the Don and the Dnieper, and making many victims at Kieff, where the river water is used to furnish the town's supply. Many other streams and waterways were polluted by drainage from cholera-stricken towns, and by the dejecta from sufferers on board the floating craft. However, by the end of 1907 the ravages of the disease began to slacken, and in February, 1908, Russia was understood to be clear of it. Once again in the following summer it reappeared in the valley of the Volga, and claimed more victims than in the preceding year. The same ill-fated districts in the south and east were attacked, and many new

ramifications marked the progress of the epidemic, St. Petersburg, for example, being very severely visited. In the capital there were no less than 2,600 deaths between September 11 and October 10. There was again a marked abatement during the winter, the fresh cases reported monthly declining from 3,000 in October to 400 in March. Cholera apparently refused to be entirely stamped out during the spring of 1909, and once more in July it began to rage with increased virulence. From June, 1908, to April, 1909, there had been 30,000 cases notified and 13,000 deaths. To stamp out the germs of cholera when once it has become epidemic over a wide area, and after millions of vibrios have been disseminated over the land, is a task of supreme difficulty. The utmost efforts of the Russian Government from 1907 to 1909 failed to rid the Empire of cholera, and in 1910 its ravages were, if anything, more sweeping than ever.

Chemical Changes in Stored Water: Dr. Houston's Researches. — There are, however, other changes which proceed in the reservoirs wherein river water or surface water is impounded, which are of much interest to the student of biochemistry. These changes are almost all in the direction of betterment so far as the potability of the water is concerned. In his Third Research Report (February, 1909), Dr. Houston continues the results of his investigations, and shows that in every case the stored water in the Metropolitan reservoirs contained much less ammoniacal nitrogen* than the raw. The average reduction for the Thames water would appear to be about 36 per cent., and for the Lea water 52 per cent. As regards the "oxygen consumed," or, rather, absorbed from permanganate (in three hours at 27° C.), the stored water again shows results from 20 to 30 per cent. better. The oxidized nitrogen (nitrites and nitrates) is diminished very considerably, especially in the case of Lea stored water (44 per cent.). In all cases the total "hardness" diminishes. We are to conclude, therefore, that changes of a physico-chemical nature are in progress in reservoirs impounding river water. These may be due to the activity of living things—algæ, plankton, bacteria—and to fermentation of dead matter accumulating on the sides and bottom, or to other agencies that cannot be definitely specified.

* Nitrogen of the so-called "free" or inorganic ammonia—NH_3 and its compounds.

. some light in regard to this alteration which uces upon river water from p. 10 of Dr. Houston's earch Report, where it is stated that the albu-rogen * suffers no diminution in the case of Lea is actually increased for Thames water in the t Staines and Lambeth. Only at Chelsea Reservoir decrease (29 per cent.). Now, it is pointed out ouston that the albuminoid ammonia test is an ne—that is to say, the chemical process employed h furnishes only a general idea of the amount of tter present. Accepting this view (see also Thresh, turn to the analysis for total organic nitrogen, and termined for two samples. We find in the case of that there is a moderate diminution of the total ogen (5 to 13 per cent.) during storage. Yet in very samples the albuminoid ammonia on being howed an increase of 40 per cent.

Causes of the Chemical Changes.—Gathering up elative to the change that comes over stored water he *decrease* of ammoniacal nitrogen, the decrease consumed, of total hardness, and of oxidized ne may hazard a suggestion as to the probable work in the particular waters here under con- But first we shall consider how far these chemical related to the season of the year.

and III. show the summer and winter averages, ormer from May 1 to September 30, and the latter r 1 to April 30.

TABLE II.

AMMONIACAL NITROGEN, PARTS PER 100,000.

Water.	Winter.	Summer.
.. .. ..	0·0083	0·0030
th	0·0048	0·0043†
.. .. ..	0·0028	0·0013
.. .. ..	0·0051	0·0038
.. .. ..	0·0139	0·0064
.. .. ..	0·0048	0·0055

organic compounds, which can be estimated as ammonia in

† May, June, July only.

Thus, there is more ammoniacal nitrogen in the raw water in winter, and the decrease due to storage for Thames water is 50 per cent. on the average of three reservoirs, and for Lea 65 per cent. In summer, with less ammoniacal nitrogen in the raw water, the amount increases in two instances in Thames stored water (though it is steady on the average of the three), and decreases slightly in Lea water.

TABLE III.

ALBUMINOID NITROGEN, PARTS PER 100,000.

Water.	Winter.	Summer.
Raw Thames	0·0164	0·0138
Stored Lambeth	0·0152	0·0217
Stored Chelsea	0·0107	0·0109
Stored Staines	0·0233	0·0191
Raw Lea	0·0152	0·0159
Stored Lea	0·0135	0·0182

The albuminoid ammonia in Thames water is greater in amount during the colder period of the year, and it diminishes very considerably when stored at Lambeth and Chelsea. But Staines shows a rise of 42 per cent. The summer albuminoid ammonia increases at Lambeth, and also again at Staines, by 30 per cent. under storage, and falls away by 22 per cent. at Chelsea. In Lea water the winter and summer albuminoid ammonias are nearly equal, but there is a diminution of 11 per cent. in winter through storage, and a rise of 14 per cent. in summer. So far, then, as this constituent is concerned, we may say that the tendency seems to be towards a decrease in winter and an increase in summer.

From October to January the ammoniacal nitrogen in raw Thames water increases four or five times over, and it sinks to near its summer level in the following May. Its material decrease in the reservoirs during the colder part of the year is in all likelihood due to the activity of certain vegetable forms,* and to the fact that there is less thrown off by fermentation and decomposition among the sediment when the general temperature is lower. That there is less ammoniacal nitrogen in the raw water during the summer follows from

* For the action of Nitrifying Bacteria see pp. 63, 66, 280.

the circumstances that the water-level in the gathering area is lower, and surface supplies send much less abundant contributions. The average number of microbes of all kinds in the raw water during the warmer months (May to September) is less than one-fourth of the average for the whole year.

The tendency of the albuminoid ammonia to decrease in stored water during the winter is probably due to the fact that many living things which might thrive and multiply in warmer weather subside with the general fall of sediment. Much finely divided organic matter that has been carried away by surface water by autumn and winter rains will also fall out. To a large extent the contamination of surface waters is absent in summer, so that one would anticipate a lower content of albuminoid nitrogen from May to September. That the albuminoid nitrogen shows in general a tendency to increase under storage in the warmer period points to the more vigorous growth of animal forms in the reservoir waters.

We have seen that the ammoniacal nitrogen is quite as abundant in the reservoirs as in the raw water during the summer; and though plant forms must be continually making use of it, the supply is no doubt maintained by the fermentative changes which develop in the deposited sediment. In it the organic matter is daily replenished from the impurities which the incoming water conveys, as well as from dead organisms which have completed their period of existence in the reservoir.

Relative Amount of Ammoniacal and Albuminoid Nitrogen.—Dr. Houston calls attention to the ratio of ammoniacal to albuminoid nitrogen in the raw and stored Lea water, and shows that for the former the ratio is 69 : 100, and for the latter 33 : 100 on the average. There is a special significance in this which becomes more apparent when we consider the summer and winter ratios. For the raw water these are 44 : 100 (summer) and 90 : 100 (winter), and for stored water 31 : 100 (summer) and 35 : 100 (winter). In the colder season the amount of albuminoid nitrogen draws very close (it is in excess, as a matter of fact, for January and February, 1908) to the ammoniacal in raw Lea water, but storage reduces the ratio by no less than 55 per cent. The reduction for the summer months is from 44 to 31—that is, 30 per cent. In other words, while both albuminoid and ammoniacal nitrogen are

reduced by storage, the latter diminishes much more quickly than the former, especially in the colder months. The agency which withdraws so large a proportion of the ordinary ammonia (or ammonia salts) without affecting the actual amount of albuminoid matter to any great extent must be looked for in the vegetable life of the reservoirs.

We gain some further insight into the vital activities which are at work in these reservoirs by a consideration of the oxygen-consumed test. This is now believed to furnish a measure of the carbonaceous part of the organic matter without specially signifying whether such carbon is derived from plants or animals. The winter and summer averages (using the terms in the same sense as above) are given in Table IV.:

TABLE IV.

OXYGEN ABSORBED BY PERMANGANATE, PARTS PER 100,000.

Water.	Winter.	Summer.
Raw Thames	0·2586	0·1561
Stored Lambeth	0·1883	0·1710
Stored Chelsea	0·1754	0·1240
Stored Staines	0·1817	0·1296
Raw Lea	0·2155	0·1613
Stored Lea	0·1336	0·1259

Thus, it appears that there is a reduction of 30 per cent. from raw to stored in the winter for Thames water, and of 38 per cent. in the case of Lea water. In summer, again, the corresponding figures are 19 per cent. and 22 per cent. We conclude that the decreased percentage of reduction during the warmer part of the year is traceable to the fact that the warmer weather is more congenial to the growth of plants which draw supplies of carbon from the air dissolved in the water.

Referring to Table I. (p. 31), which shows the effect of prolonged storage on surface water, it will be seen that free ammonia diminishes by 70 per cent., albuminoid by 25 per cent., and oxidized nitrogen by 37 per cent. On the other hand, oxygen consumed remains about steady, showing at times a slight improvement.

Chemical Changes in River Water stored under Laboratory Conditions.—In order to throw light upon the changes which

occur in stored river water, Dr. Houston made a series of experiments of the following nature (Third Research Report, pp. 12, 13). Samples of Thames and Lea water, along with their proper sediment, were placed in bottles, partially filling them. The bottles were plugged with cotton-wool, and set in a room with a northern exposure. The temperature ranged from 10° C. to 21° C. The samples were left for about five weeks, and then subjected to analysis. Preparatory to this operation the bottle containing the sample was shaken up. In one set of experiments the sediment was allowed to subside again; in the second set the turbid water was immediately withdrawn. Dealing first with the experiments to which no sediment went to analysis, it is observed that the ammoniacal nitrogen almost entirely disappears, the average loss being 94·4 per cent. Albuminoid nitrogen sinks by 33·6 per cent., and oxygen absorbed by 30 per cent. With regard to the samples which were shaken up before being analysed, it is again observed that the ammoniacal nitrogen has practically vanished, about 6 per cent. only of the original amount being left. Albuminoid nitrogen suffers a smaller decline—namely, 21·8 per cent.—and the oxygen absorbed only 16·3 per cent.

Under the conditions of these tests, abundant opportunity was given to the living things present in the raw waters to continue their development. Many lowly forms thrive well under such circumstances, and the disappearance of ammonia salts was doubtless due to this form of life. The decomposition progressing among the sediment would release more ammonia as a by-product, and would tend to lessen the percentage of albuminoid matter. The analyses recorded show that 12 per cent. of the original albuminoid nitrogen still remains in the sediment. In like manner it appears that 14 per cent. of the oxygen absorbed in the raw sample can be determined in the matter deposited after the lapse of five weeks. Of the whole albuminoid nitrogen present at the beginning, 66 per cent. still remains either in solution or in the bodies of animalcula and minute plants which are suspended in the water.

Storage, then, under laboratory conditions is more beneficial to the water than is the impounding in the London reservoirs. But in truth, under the conditions of the two sets of experiments, the results are not directly comparable, seeing that there may possibly have been a considerable admixture of

recently pumped water with many, or even most, of the reservoir samples. Further, as Dr. Houston points out, the sides and bottoms of the reservoirs are always covered with deposits, which by their fermentative changes influence the chemical aspect. It would appear to him that advantage might result if the raw water were first put through a sedimentation basin, or roughly filtered after the Puech-Chabal system, whenever the sources are unusually turbid. The twin sets of experiments which were made seem to indicate that this recommendation is sound.

General Conclusions.—It is not to be overlooked that the foregoing discussion has immediate reference to the storage of river water, but there can be no doubt that any supply composed largely of surface water, contaminated more or less with sewage, would under storage exhibit corresponding changes. The impounding of water from deep springs and wells, and from other sources that are ordinarily beyond the reach of pollution, is a step which is justified by the exigencies of supply and demand, and not by any expectation that the quality of the raw water will be improved. It may even happen that over-abundant growths of algæ in the reservoirs will tend to a deterioration of their contents, but if care is taken to anticipate excessive development among the algoid forms by the use of very small doses of copper sulphate, there need be no serious anxiety regarding this matter.

The benefits accruing from the storage of river water are largely influenced by local circumstances. A certain fraction of the ordinary flow of the stream is abstracted, and the larger this fraction is, the more difficult it is to make a selection of the best water. This is especially the case where the reservoir is fed from a pumping-station, but it is very often not easy to build up a reserve when conditions are favourable.

When flooding occurs, the supply is interrupted for a time, during which the volume of water in the reservoir is continually decreasing. The filters, as Dr. Houston says, are then borrowing on capital. The subsequent replenishment with crude water produces a mixture of raw and stored material which is undoubtedly very different from the normal. Unless storage has been provided equivalent to the volume of service water required for a lengthy period, say, for three months, the

recurrent irregularities in the quality of the intake cannot fail to show their effect on the subsequent process of filtration, and therefore on the purity of the effluent which goes to service.

Not only is the water taken in after a flood likely to be more than ordinarily polluted, but it is called upon to meet the daily requirements after a shorter term of purification under storage than the crude water normally receives. Where there are likely to be pronounced irregularities in the quality of the water which is distributed to the filter-beds, Dr. Houston considers that water authorities might turn their attention to supplementary processes of purification (Fourth Report Metropolitan Water Board, 1910, p. 29).

It has been asserted by some authorities that the construction of reservoirs large enough to insure for the raw water a halt of about three weeks before passing to the sand-beds is an unnecessary addition to the initial expense, seeing that efficient filtration removes all the objectionable matter, and yields an effluent which is of even quality, no matter what the state of the raw water may be. Speaking generally, there is some truth in this contention, but filters are by no means perfect machines, and in the presence of adequate storage it is most reassuring to have the knowledge that, even should a filter-bed function badly for a time, there will be no serious harm to the consumers. To those who systematically analyze the output of filters it must be well known that the efficiency varies, and that, out of a group of a dozen, one or two may from time to time function badly without apparent reason. This very circumstance was pointed out to the writers at Antwerp Waterworks by Dr. Kemna. Two of the beds had been giving results much poorer than the others, as was, indeed, evident from a glance at the turbidimeter. As, however, the raw water had been twelve hours in a sedimentation basin with coagulants, and had subsequently been roughly filtered after the Puech-Chabal system, the manager had no anxiety regarding those temporary defects. Dr. Houston lucidly sums up the advantages which he has proved to accrue from storage, and his conclusions are here briefly recapitulated:

1. The microbes of disease, and those which are indicative of sewage (*B. coli*), perish rapidly in stored water. In about three weeks, generally speaking, the safety change is com-

plete, and the dangers imminent from sewage pollution are minimized.

2. After being impounded for two or three weeks, the water is in a better state from a chemical point of view, seeing that there is a well-marked decrease of ordinary ammonia, oxygen consumed, oxidized nitrogen, lime salts, and occasionally of albuminoid nitrogen.

3. Storage deprives the raw water of nearly the whole of its sediment, and therefore serves to prolong the life of the filter-beds.

COPPER SULPHATE TREATMENT OF PLANT GROWTHS.

During the warmer months of the year it frequently happens that algæ and minute plant species increase in the reservoirs to an extent which is both harmful to the quality of the water and unfavourable to its filtration. Certain species of water-plants give rise to disagreeable effects, notably the blue algæ, *Anabœna* and *Uroglœna*, which during their decay disseminate oily matters with offensive smell. When the water is loaded with an excessive growth of minute forms (plankton, etc.), the life of the filters is shortened. Not infrequently (as at Antwerp) the filter basins themselves show a tendency to become choked up with rank growths of algæ, so that the period of working is decreased. Much difficulty has been experienced in America on account of these water-plants. They do not flourish so vigorously in spring waters, but they favour river and surface waters containing a good deal of ammonia and other ingredients washed from the land. The result is that such waters may actually deteriorate under prolonged storage, and many of the good effects that follow from a few weeks' quiescence may be counterbalanced by the undesirable consequences of abnormal plant growth.

One at least of the considerations which have led water undertakers to adopt a method of rapid sedimentation is the possibility of trouble arising from these cryptogamic growths. Exclusion of light would also arrest their development, but this may be regarded as unfavourable to bacteriological purification, and on the score of expenditure it may be impracticable. The procedure which is most generally applicable without entailing any considerable outlay is that of treating the impounded

waters with a suitable chemical, which will check the plant growth, and yet leave no residue appreciable to the consumer.

Experiments with sulphate of copper have been made in America, England, and many other countries, and it has been shown that a very small dose of that substance will effectively arrest the growth of algæ. One part in ten millions is algicidal, and if this exceedingly small proportion be added to the reservoir in anticipation of growths which have previously given trouble, there will be a prevention which is here much better than a cure after the evil has developed. For the addition of copper sulphate to a reservoir or filter-bed choked with algæ results in the death of myriads of living members, which straightway commence to decompose and foul the water with the resulting products. If blue algæ are present, the chemical applied ruptures the oil-sacs, and the smell which proceeds from the water is temporarily many times worse than before.

Dr. Kemna's Experiments.—The following statement by Dr. Kemna regarding the application of copper sulphate to a filter-bed at Waelhem is of interest. There had been a most abundant growth of algæ, which brought the filters to a standstill after a brief run. The sulphate was added on August 4 and 5 at the rate of one part per million, from August 6 to 13 at half the above strength. Not until August 12 did the manager consider it desirable to accept the effluent of the filter-bed for service use. During the first four days (August 4 to 7) the ordinary ammonia in the filtrate increased. It then began to diminish, and the normal condition on this respect was reached about eight days later. In the meantime the filter gradually became obstructed by the dead organisms, and it could be run for only four days after restarting ; it was cleaned on August 16.

Most noticeable was the circumstance that the number of microbes which passed through the filter rose quickly soon after the treatment was begun. The effluent was, indeed, very bad on the fourth, fifth, and sixth days. Dr. Kemna explains this fact in stating that the dead algæ afforded material for an enormous increase in the number of bacteria at the surface of the filter-bed (see also p. 95). However, within a few days more the filter resumed its normal efficiency. The decom-

position of dead filaments was at an end, and the bacteria, lacking food, decreased steadily, to the advantage of the effluent.

Method of applying Copper Sulphate.—Water engineers who have knowledge of this mode of treatment have found that it answers better to add the chemical in two doses. The first disposes of species which more readily absorb the copper sulphate, and when these are destroyed the second application reaches the others with greater certainty. The sulphate may be introduced into a reservoir in the following way : A weighed quantity is tied up in canvas bags, which are towed from side to side so as to make a fair distribution. With filter-beds spraying may be resorted to, or the solution may be added to the inlet by a perforated pipe, or a bag containing the crystals may be submerged in the water which comes in.

It is evident that the copper sulphate treatment applied to a reservoir already beset with algoid growths occasions a certain amount of inconvenience, and renders the water unsuitable for consumption for a number of days. Unless the use of the reservoir can be dispensed with for a week at least, the treatment is to be advised with much caution. It has been found from experiments in America that the bad odours arising from the disintegrating algæ disappear, but some time is required. The treatment has this to recommend it, that its influence possesses a degree of permanency. Algæ grow only with reluctance for a considerable period subsequently. The after-effects continue, and are appreciable in the case of filter-beds after several cleanings. There may be difficulty at first in obtaining a satisfactory film, for the precipitated copper appears to linger in the sand-bed, and even in this passive state to inhibit the growth of algæ to some extent.

As already stated, copper sulphate should be applied more as a preventative than a cure. This is Dr. Kemna's opinion. By regular use of the plankton net, one can judge with accuracy regarding the condition of the reservoir water. Each case requires special examination and consideration, for some waters are able to take larger doses than others. The presence of carbonate in solution tends to precipitate the sulphate of copper as carbonate, and thus to reduce its algicidal potency. To what extent the above reaction actually occurs with very dilute

solutions has not been determined. Carbonate of copper at any rate is slightly soluble in ordinary waters. Dr. Hewlitt thinks that the copper is quickly thrown down as oxide or carbonate. It may be that in the highly diluted condition the copper sulphate dissociates, the copper or basic ion being absorbed by the algæ, while the acid radical combines with dissolved carbonates.

Filtered Water is not affected by the Copper Sulphate.—However this may be, it would seem that the filtered water contains no trace of copper even when doses of 1 part in 2,000,000 have been employed. It may be difficult to obtain proof of the absence of a trace of copper in the effluent, and there would seem to be no ground for supposing that infinitesimal quantities have the slightest effect on the health of the consumers, especially as any contamination from this source would be temporary. Dr. Rideal, however, appears to have a doubt regarding the total elimination of the copper salts, and he prefers to apply another chemical. There is no serious objection to the use of a hypochlorite or free chlorine on the score of after-effects. Only a very slight increase of the total amount of combined chlorine results, and this is in no way harmful. As will be seen (p. 198), a very small percentage of hypochlorite serves to destroy bacteria. It is also strongly algicidal. A solution of bleaching lime of suitable strength can be applied to the reservoir water by spraying, or by a suitable conduit at the intake, or by other methods, as may prove convenient. It is found, however, that in sunny weather the dose of hypochlorite has to be largely increased. Again it may be said that the treatment should be in anticipation. No matter what chemical is applied, there will be the objectionable consequence of destroying dense overgrowths of plants, resulting in the suspension of the use of the reservoir for a time.

CHAPTER IV

CONSTRUCTION OF RESERVOIRS AND CARE OF FILTERED WATER

WATER engineers are in agreement as regards the leading principles of reservoir construction. One of the main objects in view being to discourage the growth of water-plants and algæ, the whole extent of the reservoir should be made as deep as possible, and never less than 25 or 30 feet. For the same reason the sides are to be perpendicular, or as nearly so as may be practicable, in order to restrict the width of the shallow margin on which algæ grow most profusely. The deposited sediment will not collect on the steep slopes, nor afford pabulum for plants to germinate in.

Many modern reservoirs (*e.g.*, Selby) are lined throughout with concrete over bitumen sheeting, and others are built of reinforced concrete (Suresnes), but in the case of very large constructions the question of expenditure would set this excellent method aside. When, however, a dam is formed by impounding the waters of a valley, a judicious selection of the site is a matter of the first importance. The sides should be pitched with set rubble, or laid with cement to a depth well below the probable low level. This further serves to protect the banks from the action of waves during windy weather. Deeper down the sides may be laid with loose stones. The bottom should be cleared of vegetable matter, and during construction every care should be taken to keep the bed of the reservoir free from excremental material. It is a good plan to fill up the newly-made reservoir with water, and allow it to run to waste after standing a few days. Bottom growths do not occur in deep reservoirs, but sediment, of course, accumulates apace if turbid waters are admitted. If the suspended matters which subside amount to 30 grains per gallon, and the reservoir water

is renewed once in ten days to a depth of 20 feet, each square foot of the bottom will receive a deposit of 3 pounds of matter per annum. Part of this, being organic, may be removed by decomposition and solution, but there will be a permanent yearly addition, which may amount to a foot in twelve or fifteen years. The greater portion of the suspended matters precipitates near the inlet, and tends to reduce the depth there more rapidly.

It has been recommended that the intake of reservoirs be guarded by catch-pits to intercept the heavier portion of the sediment. These can be cleaned out very easily when occasion demands.

In order that the freshly admitted water may remain as long as possible in the reservoir, and may not become mixed with the outflow to the filter-beds, it is important that the outlet and inlet should be as far removed from each other as possible. It is bad policy to have the inlet and outlet in the same tower. Reservoirs which are capable of holding supplies for one or two days should be divided, so as to insure a period of quiet, more especially during the times when the intake is unusually turbid.

Dr. Houston distinguishes between active and passive reservoirs (Third Research Report, p. 3), the latter, not recommended by him, being used to conserve a considerable volume of water as a stand-by, while the raw water in ordinary circumstances goes to the filters. Such passive reservoirs may be perfectly appropriate under certain circumstances, enabling the water manager to shunt storm-water and to supplement the natural sources in time of drought; but wherever the raw water is subject to surface pollution, the active reservoir through which the whole supply must pass is the one worthy of recommendation.

Reservoirs with Compartments in America.—There are several advantages of dividing the storage area into compartments. The grosser sediment is mostly collected in the first basin, and this (or any one of the other units) may be cleaned from time to time without interrupting the work of the other basins. The arrangement would also seem to afford greater security against the freshly admitted water finding its way to the outlet without enjoying the normal average period of storage. Unusually turbid supplies may be confined in the

first chamber for a longer period, or a coagulant may be applied. One of these reservoirs constructed at Kansas, U.S.A., is represented in Fig. 2.

Progressive Sedimentation.—Where the main object is to get rid of the larger portion of the sediment of a turbid water in limited space and time, it has been found advantageous to induce a continuous and progressive sedimentation by means of slow movement, with frequent change of direction. The best installation of this kind is that of the Compagnie

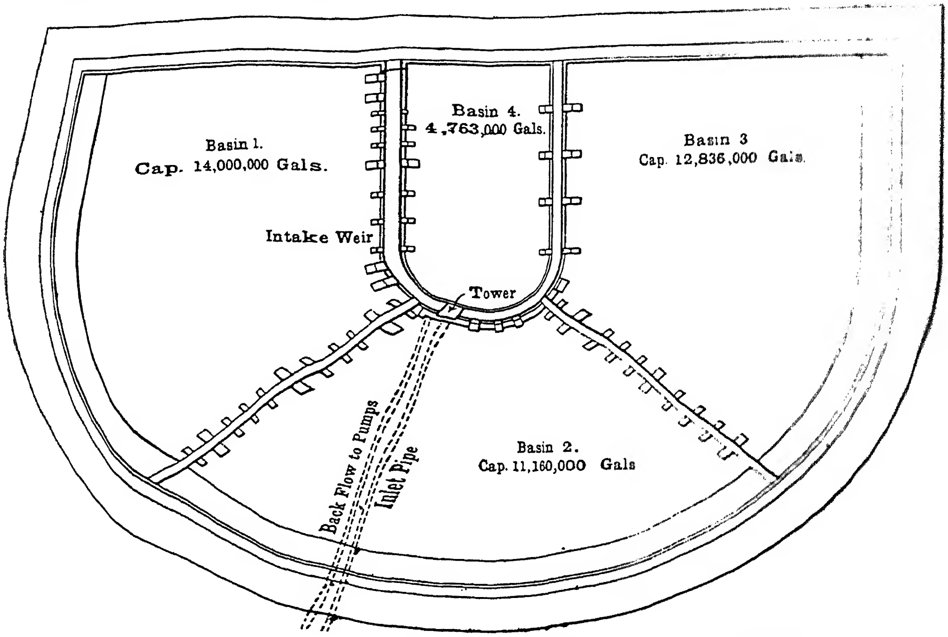


FIG. 2.—SETTLING BASIN AT KANSAS CITY, U.S.A.

Générale at the Paris Waterworks. First the water descends into a set of narrow troughs, and its flow is directed alternately to right and left, making numerous turnings. These troughs are made of concrete, and there is a slight fall from each zigzag to the next. The heavier sediment falls down abundantly. In sequence to the troughs comes a series of wider channels or basins so constructed that the inflow and outflow currents are always in opposite directions. The rate of flow has diminished considerably, and sediment of a finer grade now

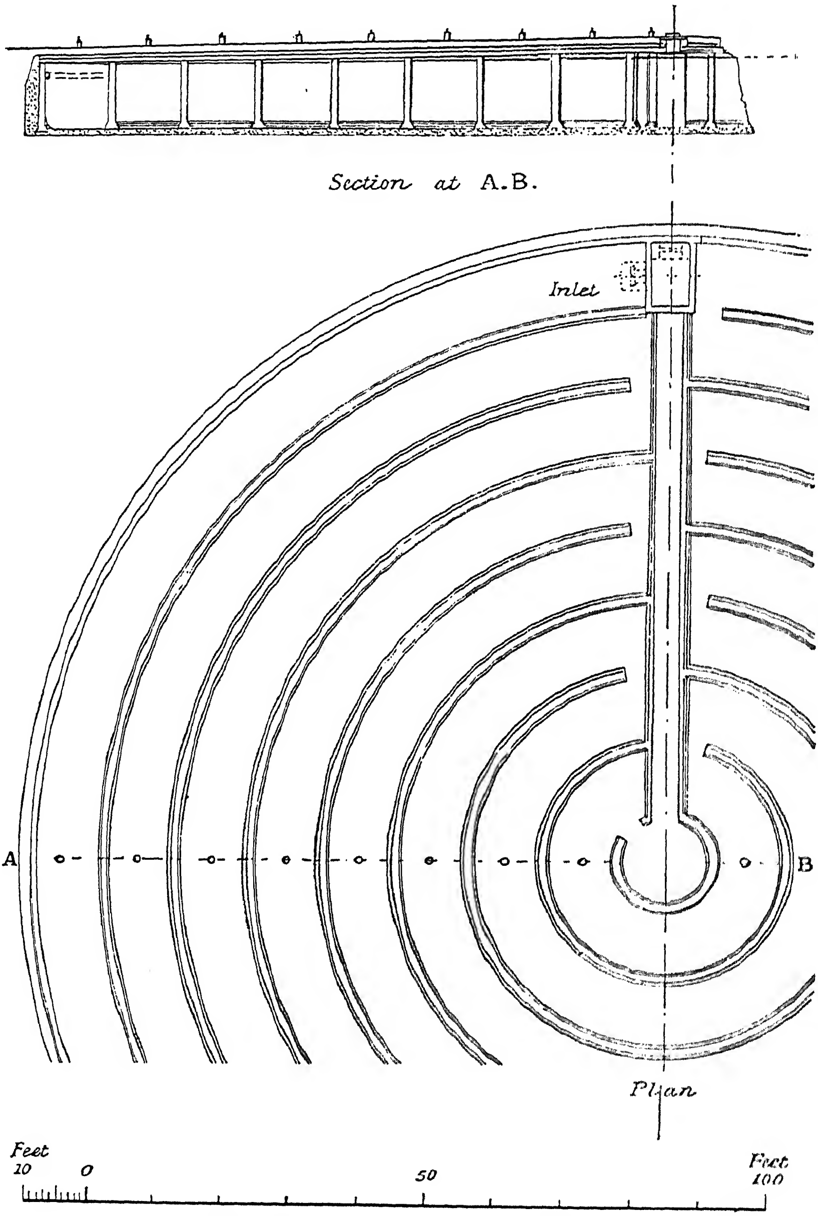


FIG. 3.—SUNDRIDGE PARK CIRCULATING RESERVOIR.

settles. Lastly, the water reaches a train of decanting basins, which are divided up into numerous compartments by means of baffle-walls (*murettes*). These latter are so constructed that the water must flow over one and under the next in order. On the whole, this sedimentation is satisfactory, and much more rapid than if the water were kept stationary for an equal period. At the particular installation here referred to, the river water has passed through the Anderson cylinders before it is transferred to the settling troughs, so that the mixture with iron oxide accelerates any precipitation which might naturally occur. Slow movement with change of direction not only promotes the silting out of suspended matters, but it also prevents very largely the growth of algæ. Trouble is sometimes caused in deep reservoirs by vertical currents, which are set up after any considerable fall of temperature in the surface stratum, and such are avoided by the present system. There is also a material reduction of the germ content of the raw water during the rapid sedimentation, but of course the main duty of eliminating offensive bacteria rests with the filter-beds.

Circulating Reservoirs.—Circulating reservoirs have been constructed at several waterworks in England for the purpose of storing water which is derived from deep sources, and is sufficiently pure to be used without filtration. The construction of Sundridge Park Reservoir is shown in Fig. 3, and it will be observed that the water circulates first counter-clockwise round the outside annular space, and then backwards in the next channel. The outlet is central. The object aimed at by drawing the water round these circular channels is, according to the engineer, that of keeping the water fresh, and preventing it from becoming dead and insipid. The growth of fungi on the walls is also avoided.

Reservoir Surroundings.—Land in the immediate vicinity of stored water should receive careful attention, and every precaution must be adopted to prevent the access of objectionable matter. It has been recommended that a belt of ground 50 to 100 yards wide all round should be acquired and planted with pines or shrubs which do not throw down an abundant crop of leaves in the autumn. This will protect the waters to some extent from dust blown from highroads and from

cultivated fields. The margins of the reservoir should be kept clear of grass and weeds. By means of suitably-placed channels, surface water draining from adjacent agricultural grounds in flood-time is to be carried clear away.

The constructions made to impound water may be classed according to the object they are intended to serve—namely, for the storage of raw water, for the purpose of a brief period of sedimentation with or without coagulants, and lastly for retaining a reserve of filtered water. It is of great moment that the latter should be properly constructed and protected from all possible sources of pollution.

CARE OF FILTERED WATER AND OF SERVICE WATER IN GENERAL.

It is an undeniable if somewhat disconcerting fact that filtered water is very liable to deteriorate if kept for any length of time before being distributed. The same is true of water drawn from springs and deep wells. Stored in an open reservoir, water of excellent quality may be invaded by plankton and micro-organisms which would render it unpalatable to the consumer. New reservoirs are generally exempt from such visitations, but soon the side-walls and bottom become seeded with minute plants, and under favourable conditions an abundance of living things pervades the whole contents. Whipple instances the case of a Brooklyn reservoir in which the microscopic *Asterionella* increased to such an extent that each cm^3. contained many thousands. Algæ and diatoms are most to be feared, particularly the latter, if there be much mineral matter in solution. The obvious remedy for algoid and plankton growths is to exclude light by covering the clear-water reservoirs. This plan has been followed at many installations, as at Paris, London, Antwerp, Eltham (for pumped spring water), Nancy, Bedford, etc. Without this precaution it is difficult to maintain the purity of filtered water. Germs drop from the atmosphere or are carried by wind. Thus the reservoir becomes a gathering ground for micro-organisms. In the absence of light, blue and green algæ, and most of the plankton species, cease to grow. It is a distinct advantage to keep the water in motion if the clear-water basin is uncovered, and it has been found useful

to do this when the water is stored in the dark (see Circulating Reservoir, p. 51). At most of the principal waterworks filtered water is stored in covered basins. The largest in the world is that for the Metropolitan supply at Honor Oak. Mr. Bryan, Chief Engineer to the Board, has expressed the opinion that filtered water should not again see the light till it issues from the consumers' taps.

Increase of Germs in Filtered Water.—What seems at first sight to be a peril to pure waters, whether filtered or drawn from springs, is a revival of bacterial activity. The germs which have escaped from the filters, or which are naturally present in deep well waters, may increase many times in a brief period. At Poughkeepsie Reservoir, New York, the filtered water stored in the light failed to preserve its bacteriological purity. The organisms in the reservoir far exceeded in number those in the raw water. The average count per cm^3. in the latter for the summer months was 180, while for the reservoir the number had risen to 1,100.

Later it will be indicated that it is only the harmless germs which undergo this multiplication. Pathogenic microbes eventually yield to the influence of storage, no matter whether the water is filtered or *unfiltered.*

Rapid Growth of Germs in Spring Water under Storage.—According to Dr. Miquel ("Manuel Pratique d'Analyse Bacteriologique des Eaux," Paris), spring water shows a remarkable tendency to deteriorate when kept for even brief periods. At a temperature of 25° C., Vanne spring water which contained 150 bacteria per cm^3. was found to be swarming with germs after twenty hours, as many as 30,000 per cm^3. being common. Dr. Frankland mentions a similar experience in the case of water from a deep well in the chalk. This contained less than 100 germs per cm^3., but after standing one day *in the dark* at 25° C. each cm^3. had more than 100,000. Leone at Munich, by keeping the supply water in sterile flasks for a few days, proved that the trivial number of bacteria originally present multiplies to tens of thousands per cm^3.* Using water from the Lake of Zurich, Cramer showed that an enormous increase of bacteria takes place every day for a week or longer, and that eventually a maximum is reached. After that there is a

* See also *Zeitschrift für Hygiene,* vol. i., 1886.

gradual decrease. It may further be said this observation was confirmed by Dr. Miquel, who emphasizes the rapid development of germs in spring water, the maximum being reached within a week. He also states that the decline is almost equally prompt up to a certain point—that is to say, till about nine-tenths of the maximum number of germs have disappeared. The subsequent decrease was always much more gradual, so that after seven weeks the bacterial content was still far beyond that of the freshly-drawn water.

Dr. Miquel further demonstrated that crude river waters containing a rich flora of microbes show but little tendency to increase their bacterial content, while if the water is running clear and comparatively pure the same faculty of rapid multiplication is invariably manifested by the germs present. The behaviour of filtered waters depends to some extent upon their previous history. If they have supported a rich crop of bacteria before filtration, they are less able to nourish the same species, and the water seems, as it were, to have become immune. But such immunity is not to be looked for save in special cases, and at best it may amount to checking the growth of one or two species.

We may therefore conclude that bacteria have the power of multiplying vigorously in all kinds of water usually distributed to consumers. This faculty of rapid increase is greatly enhanced by high temperatures, and astounding figures have been occasionally obtained after one day's incubation at blood-heat. Most of the experiments referred to above were arranged at 25° C.—that is, at a temperature which would only be reached in this country exceptionally, and in the warmest weather. But Dr. Frankland found that multiplication goes on even when the sample is placed in a refrigerator, and Kruger (*Zeitschrift für Hygiene*, vol. vii.), working at 10° C., showed that the bacteria increased five times in twenty hours. The authors have dealt with samples of filtered surface water containing on the average 107 germs per cm^3., and after incubation in the dark for one day at 10° C. found the average number had mounted to 433.

Experiments made at Massachusetts prove that the purest water—*e.g.*, water which has been sterilized by boiling—is highly susceptible to contamination. It has been suggested that boiling destroys the substances which serve to give the

water some degree of immunity from bacterial attack. The vital activity of micro-organisms produces toxic compounds which are unfavourable to their multiplication.

Difficulty of protecting Filtered Water from the Multiplication of Germs.—However that may be, it is evident that the care of service water is a matter of difficulty, and the prevention of a material increase of the bacteria may be difficult or impossible. Exclusion of light will not avail. That, of course, saves the water from contamination by aerial microbes, but it seems to have little influence on the possibilities of increase on the part of those conveyed by the water itself. A low temperature inhibits growth to a marked extent, and restrains the vitality of the germs, so that the multiplication may only attain to three or four times in twenty-four hours.

It is agreed among the authorities on this subject that the susceptibility of different waters to microbial increase after purification is widely divergent. Water undertakers should ascertain by frequent tests at all seasons how far the service water deteriorates, and the tests made should include the examination of tap water as it comes into the hands of the consumer.

Dr. Rideal found that *B. coli* increased in the water of a pure mountain stream when he infected samples with that bacillus. The increase was noted after two days' storage, and on the fourth day *B. coli* began to disappear. On the other hand, his tests made on the River Dee water, which is considerably polluted, failed to show any increase of *B. coli*. He concluded that chance infection of the pure mountain water would cause a multiplication of the germs he had under observation (see his evidence on the Aberdeen Water Bill, 1910).

It is a familiar fact that spring water gets stale in less than a day when kept in vessels, particularly in warm weather. This is partly due to loss of aeration ; but after consideration of the experimental work recorded, we can hardly doubt that there is a deeper cause at work. What is true of spring water applies to waters of excellent quality brought from mountain lakes and streams. Glasgow receives water from Loch Katrine, and in this the bacterial content is inconsiderable. But if a sample be kept for two days at 10° C., there is a large development of germs. Dr. Frankland found nearly 800 per cm^3. under these conditions (Proceedings of the Royal Society, 1893).

Influence of Organic Matter on the Growth of Bacteria.—Organic matter encourages the multiplication of bacteria, but the absence of it does not prevent it—at least for a time. This has been fully demonstrated by a number of Continental experts. Bacteria were introduced into distilled water, and precautions were taken to exclude traces of organic substances. In all cases the growth was large, and it appears that the multiplication of certain species of germs is independent of putrescible substances. Rosenberg, however, discovered that there is a great possibility of ordinary water germs dying out quickly in distilled water, even though they may have increased very much at first (see *Archiv für Hygiene*, 1886).

Free exposure to the air would seem to be most favourable to the increase of bacteria in filtered waters. But water which is charged with carbonic acid tends to inhibit growth, and in some cases at least brings about a reduction of the actual content. It must not be assumed from this that aerated waters which are usually charged with carbonic acid are sterile, for Merkel found hundreds per cm^3. in Nürnberg seltzer water, as did Pfuhl in samples at Altona, and Slater in the aerated waters sold in London.

Effect of Ozone and Hypochlorites.—A very small percentage of ozone serves to preserve filtered water intact from bacterial multiplication. Experiments made by the authors show that bacteria do not propagate in water which has passed through an ozonizer, if the infection be introduced within three hours after the treatment. If a sample from the ozonizer be left for six hours, and especially if it has been shaken, bacteria flourish with vigour. A trace of hypochlorite or chlorine is an admirable preservative. A dose of $\frac{1}{10}$ to $\frac{1}{20}$ grain of hypochlorite per gallon is fatal to bacteria introduced there and then, and the effects continue for at least twelve hours. The chlorine slowly loses its potency, and it does this much more quickly if the sample to which it has been added is exposed to daylight. In his lecture to the Seventh International Congress of Applied Chemistry, 1909, Dr. Thresh discussed the sterilization of water by chlorine, and added that the cost would not exceed 5s. per 1,000,000 gallons, provided the water were fairly free from organic matter in suspension or solution (see also pp. 198, 199). Dr. Houston, however, was the first

to face the responsibility of sterilizing drinking water in bulk. From 1905 onwards he treated with chloros (sodium hypochlorite) the water-supply of Lincoln (50,000 inhabitants), and with highly successful results. Here, then, we seem to have one practicable method of curbing the tendency of residual microbes to multiply in clear water. An infinitesimal dose of hypochlorite, less than would be appreciable to the consumer, would seem to be the best remedy. If, indeed, there were any fear that traces of chlorine would impair the quality of the service water, these might be removed by passing the water through a rapid filter of iron borings and polarite or through a layer of coke or carbon just before it entered the mains.

Of the organisms which grow in underground reservoirs and in the distributing system, the only one that has pertinently drawn attention to itself is Crenothrix. The activity of this minute species is so detrimental to the visible character of the tap water and to the carrying power of the iron mains that steps must be taken to check its operations at very many waterworks.

The question of the multiplication of bacteria in service water has been considered at some length because the subject is generally regarded as one of great importance. Dr. Houston, however, believes that only harmless bacteria multiply, and that all the germs of water-borne disease perish in filtered, spring, and well water even more rapidly than in river water impounded in storage reservoirs.

CHAPTER V

SAND-FILTRATION

THE chief duty of a filter being that of intercepting matters in suspension, and more particularly the retention of germs of a pathogenic character, we have to consider how far the sand-filter is serviceable for the work which it is so often called upon to perform. There is no question that the sand-filter is able to remove visible sediment from almost every kind of crude water, and change the turbid flow into a transparent stream. But even when the effluent is clearest, it may contain an abundance of living specks which are only visible with the highest powers of the microscope. The ability of a filter to retain bacteria must now be regarded as the touchstone by which its efficiency is to be judged.

"The *entire* exclusion of sewage from supplies drawn from rivers," says Dr. P. Frankland,* "is practically impossible." Yet such water is not objectionable on the ground of the total organic matter which it contains, but simply because the water undertaker is aware that the source from which it comes is liable to contamination. Raw Thames water contains from 0·011 to 0·017 part of albuminoid nitrogen per 100,000, which is not appreciably beyond the limit often set by chemists to the quantity of that ingredient permissible in potable waters. Untreated Thames water could not by any means be considered potable. Filtration does something to reduce the organic content, but it is intended to perform other duties which are of higher consequence.

The work of the sand-filter may be considered from three standpoints : (1) The mechanical action of separating suspended solids ; (2) its chemical influences on matters in solution ; (3) its relations with the lower forms of life, vegetable and

* "Micro-Organisms in Water," p. 117.

animal. The effects which the filter is able to produce upon the crude water are in general the consequence of agencies that may be classed under more than one of the divisions here mentioned, bacteriological developments generally going hand in hand with chemical change, so that the term "biochemical" would appropriately designate the joint work.

1. Action of the Sand-Filter on Matters in Suspension.—When turbid water is run slowly through a bed of clean sand, all the particles which cannot negotiate the minute passages are, of course, retained, and very many of smaller grade are deposited on the granules, where the feeble currents do not readily dislodge them. The surface layer soon acquires a coating of finer and coarser particles, the interstices of which are closer than those of the sand-bed itself, so that after a time the greater part of the purely mechanical action is performed by the top layer, and little filling of the interstitial passages occurs below the uppermost half-inch. But this thin filtering sheet is able to make a turbid inflow perfectly clear and transparent, provided there be nothing in solution to cause a visible tint. That the greater part of the sediment is arrested at the superficial layer is clearly shown by the fact that the sand is discoloured to a depth of only a very few inches. Thus, the fine mud constructs the screen which ultimately hinders the passage of very minute specks.

If the sediment be to a large extent composed of very finely divided silt, the sand-filter does not operate so satisfactorily. Just as precipitated sulphur will filter through blotting-paper, so the silt of the Nile and the Mississippi and the Ganges is imperfectly retained by a sand-bed. The remedy is to apply a coagulant, as sulphate of alumina, and it is quite practicable to do this at the beginning of a run after the sand-filter has been cleaned, and so at small expense economize the time which is usually needed for filming with mud in the ordinary practice. As we shall see later (p. 145), artificial filming is employed at Egham Waterworks.

It is generally believed that the efficiency of the filtering skin is enhanced by the crop of vegetable species which soon begin to germinate in it. According to season and circumstances, it may be from two or three days to as many weeks before any marked growth of algæ has taken place. Supplies

from lowland streams and from lakes usually develop a vigorous growth on the filter-beds, while purer waters from springs and uplands do not encourage the development of algæ in the film. This may be due to the lack of certain nutrient ingredients in these purer waters, such as salts of ammonia, and nitrates, which are known to force the growth of plants. There is also little in underground or upland waters which would serve to sow the muddy film with spores or with fragments of plants. Experience with that part of the Paris supply taken from springs has shown that sand-filtration does not improve the quality of the water, bacteriologically at least. The growth of algæ on the filter is not an unmixed good ; in fact, a too abundant crop is objectionable, because it is apt to detach itself from the surface, and rise to the top in patches, carrying away the film in its train. Thus the continuity of the surface layer is broken, and the water finds an easier passage through the patches of sand exposed, and escapes without undergoing searching treatment. From spring to autumn the algoid flora are for the most part in season. Diatoms are less dependent on temperature, and are met with all the year round. We shall consider the advantages and disadvantages of plant and animal life in the sand-filter in a section dealing with the biology of the same. Meantime it is to be noted that at various places satisfactory filtration goes on without the presence of algæ. At the Amsterdam Waterworks as good results are obtained before the algæ have had time to grow as afterwards. The Puech-Chabal finishing filters at Paris run for long periods because they do not become encumbered with growths. The covered filters at Nancy do their work with a film of purely inorganic material. Covered filters are receiving favourable attention from various water authorities. Especially in warm climates, the abundant and rapid growth of algæ shortens the life of the filters, and correspondingly raises the cost of working. Largely on this account, mechanical filters have replaced the open sand-filter in America, Egypt, and India. Covered sand-filters are installed at Châteaudun, Durham, Nancy, Philadelphia, and elsewhere.

The experience of Zurich in this respect is of interest. At first some of the filters were covered at an extra cost of 27½ per cent. of the capital outlay per bed. These showed an efficiency equal to that of the open filters; and as their period of run

was one and a half times greater, and the output larger, they worked 10 per cent. more cheaply. All the filter-beds there have now been roofed over (Proc. Inst. Civil Engineers, vol. cxi., p. 282).

2. **Action of Sand-Filter on Dissolved Substances.**—The action of the sand-filter upon dissolved substances is most marked in the case of ammonia and organic matter. The latter is usually estimated by determining the albuminoid ammonia and the amount of oxygen consumed. Chlorides pass through the sand without noteworthy decrease; nitrates vary slightly, sometimes decreasing, more often increasing; sulphates and carbonates are not appreciably affected.

Free Ammonia; Decrease by Sand-Filtration.—In Chelsea stored water, the ordinary or free ammonia averaged for the year 1908-09, 0·0028 part per 100,000, while the filtered supply did not contain a twentieth of that amount. Stored Lea water sampled during the same period showed 0·004 part of free ammonia, and the filter effluent gave 0·0004 part, a diminution of 90 per cent. These remarkable results are not obtained from sand-filters in general, but they may be regarded as typical of the work of the Metropolitan installations. Indeed, the average amount of free ammonia at eleven of the Metropolitan stations in the service water for the years 1907-1909 was only 0·00036 part per 100,000. In contrast with this, the sand-filters at a large installation in Scotland often leave the free ammonia unchanged, while at other times it is reduced by one half, from 0·002 to 0·001 part per 100,000.

On first consideration it might seem that the reduction of free ammonia is due to the activity of plant growths in the filtering skin. But this cannot be the only cause, since the decrease was quite as marked in the month of December at the Metropolitan stations as at any other time. The averages are certainly higher for January to March, but even for the seven stations at which an increase over the normal occurred, the average amount was still very low, reaching only 0·0004 part per 100,000.

At the Amsterdam Waterworks the prefilters reduce the free ammonia from 0·5 milligramme per litre (0·05 part per 100,000) to 0·01 milligramme in the same volume, a reduction of 98 per cent. Yet the prefilters are under cover, and no film of vegetable

matter is formed. During eleven months of the year 1908 these prefilters removed the whole of the free ammonia. Little was left for the finishing filters to do in this respect, and but for one analysis, which showed 0·098 milligramme per litre in the service water for October (the prefiltered effluent being then quite clear of ammonia), the average for the year would have been nil.

Cause of the Reduction of Free Ammonia.—To what, then, are we to ascribe the reduction of free ammonia in the sand-filter? One cause may be the oxidation of ammonia into nitrous and nitric acid by nitrifying bacteria. According to Dibdin ("Purification of Sewage and Water," p. 12) and Rideal ("Water and its Purification," p. 171), nitrifying bacteria live in soil and water, and require the presence of animal or vegetable matter and dissolved oxygen for their action. All these constituents are present in river and surface waters. The ammonia is transformed by these organisms into oxides of nitrogen, which may be estimated in the effluent. Hence, where the ammonia has suffered a decrease, we should, on the hypothesis put forward, expect a corresponding increase of oxidized nitrogen. This is actually the case at certain water-works.

At the Amsterdam installation the oxidized nitrogen increases from 1·2 milligrammes per litre in the raw Dune water to 2·0 milligrammes in the prefiltered, and to 2·3 milligrammes in the finished service water. We saw that in this case there was at the same time a remarkable diminution of the free ammonia content. Exactly similar results are obtained with the Vecht water at Amsterdam. The free ammonia diminishes from 0·5 to 0·04 milligramme per litre, while the oxidized nitrogen rises from 2·32 to 3·92 milligrammes per litre. At Prestwick, Ayrshire, the free ammonia diminishes, and the oxidized nitrogen increases during filtration.

The statistics for the Metropolitan supplies do not in the main support our hypothesis; for although there is a decided reduction of the free ammonia, there is not as a rule any marked alteration of the oxidized nitrogen content. Here, however, it is to be remembered that the amount of free ammonia in the stored waters of the Metropolitan area is small, and the average reduction amounts to 0·002 to 0·003

part per 100,000—that is, 0·02 to 0·03 milligramme per litre. Expressed as nitric anhydride, this would mean an increase of about 0·01 to 0·02 part per 100,000 ; and as there is about ten times that amount ordinarily present in both stored and filtered waters, the difference would hardly be perceptible. This is all the more true, because the analyses issued by the Metropolitan Water Board only express the oxidized nitrogen to two places of decimals.

At the Paris Waterworks there are various systems of purification, but, of the two which depend chiefly upon sand-filtration, neither effects any decided change in the amount of oxidized nitrogen. This is shown by the reports of the "Bulletin Officiel Municipal," from which it appears that in the raw and filtered waters at Choisy-le-Roi (System Anderson) the nitric nitrogen is nearly always denoted by the same figure. This is also the case with the Puech-Chabal system at Nanterre and at Ivry. As, however, the analyses are not calculated beyond one place of decimals, and as the ammoniacal content of the crude waters is low, it is not necessary to infer that nitrification is at a standstill in the Paris filter-beds. One thing is clear from the same reports, that the nitrous nitrogen is in general wholly oxidized at all the stations.

Dr. P. Frankland ("Micro-Organisms in Water," p. 118) shows that sand-filtration increased the total nitrates in River Ouse water from 0·077 to 0·089 per 100,000. Both organic carbon and organic nitrogen decreased slightly.

It has to be remembered that some part of the ammonia on which nitrifying bacteria operate would be derived from the decomposition of organic matters present in the water, so that we may not trace the whole of the increase of oxidized nitrogen in a filtrate to the oxidization of free ammonia in the unfiltered supply. Besides, Dunbar ("Principles of Sewage Treatment," p. 150) asserts that there are bacteria which transform nitrogenous organic matter directly into nitrates. It is obvious, therefore, that there are difficulties in the way of laying one's finger upon the ultimate destination of the free ammonia which disappears in the sand-bed.

Reduction of Albuminoid Ammonia.—Abundant statistics are to hand to prove that albuminoid matter undergoes important changes in the sand-filter. Such matter is the

natural food of many saprophytic bacteria, among which may be mentioned *Bacillus termo*, several species of micrococci, vibrios, and spirilla. By the activity of micro-organisms albuminoids are peptonized, then split up into simpler bodies, as fatty acids, tyrosin, leucin, ammonia carbonic acid, marsh gas, sulphuretted hydrogen, and water. Further decompositions ensue, and, if conditions be favourable, nothing is left of the albuminoids that could be called organic, the ultimate residues being water, nitrates, ammonia, carbonic acid.

These putrefactive changes go on with ease in the soil, but they also make good progress in water. The River Seine, for example, after receiving all the organic débris of Paris, exhibits at Meulan, forty-four miles down the stream, only the slightest traces of organic impurity. The refuse of Prague, Dresden, Magdeburg, and other populous towns, discharged into the Elbe and its tributaries, did not prevent the water of that river from being used as drinking water at Hamburg, without any process of filtration, for years previous to the cholera outbreak. The River Dee in Aberdeenshire was examined bacteriologically in 1892 by Dr. Frankland. At that time it was receiving considerable amounts of raw sewage from villages situated at intervals of ten to twenty miles on its banks. It was shown that the stream was distinctly polluted, from a bacterial point of view, after each receipt of sewage, and was as regularly purified again in the course of its travel from one village to the next (see Report to the Corporation of Aberdeen, P. Frankland, 1892). At the time when Dr. Frankland made his examination, the volume of sewage from any one village was so small in comparison with the flow of water in the river that he could not detect by chemical analysis any distinct rise in the amount of organic matters in samples taken a short distance from the sewage outfall.

Destruction of organic matter goes on in the ordinary sand-filter. The raw dune water at Amsterdam contains 0·15 milligramme per litre of albuminoid ammonia, the prefiltered water 0·105 milligramme, and the finished supply 0·084 milligramme, a decrease of 44 per cent. These numbers represent the averages for the year 1908, but it may be remarked that this percentage of decrease does not vary much throughout the year. For the three winter months the fall in the content of albuminoid ammonia was 44 per cent., and for the months June to August

36 per cent. Stored Lambeth water contains (Report for 1908-09) 0·0162 part of albuminoid ammonia per 100,000, while the filtered effluent holds but 0·0055 part as the average of 234 samples. Thames stored and filtered waters show very similar decreases. With Lea water the figures are, for stored and filtered samples, 0·0146 and 0·0056, a diminution of 61 per cent.

Filtration at Paris on the Puech-Chabal system largely reduces the organic matter present in the crude water. Decreases of 40 to 50 per cent. as judged by the oxygen consumed are common (see "Bulletin Officiel Municipal," 1907-1909). Estimated by the oxygen consumed method, the improvement as between the stored and filtered waters of the Metropolitan installations exceeds 40 per cent. At Amsterdam the decrease of organic matter from raw to filtered water as estimated by the oxygen consumed reaches 40 per cent. at times, but the average for dune water is about 30 per cent. This average is maintained with the Vecht supply at the same station.

An experimental sand-filter under control of one of the authors of this volume was put in connection with a reservoir holding about 200 days' storage. When the filter was "mature," and the rate of percolation 4 inches per hour, the decrease of organic matter ranged from 35 to 45 per cent. After cleaning, the filter still caused a diminution of the organic substances, as much as 25 per cent. reduction having been noted after forty-eight hours' continuous working.

It has already been said that the final stage of the disintegration of organic matter is reached when the contained nitrogen appears as nitric acid (or combined with bases in the form of nitrates). Nitrifying bacteria are required to complete the last step from the albuminoid compounds and from ammonia, and, as these operate best in the presence of humic matter, attempts have been made to encourage their activity. Thus, at the Zurich filters a layer of garden soil 4 inches thick has been tried in the filter-bed. Much use is made on the Continent of irrigation and natural percolation through soil as a means of purifying water for household purposes. The experience of Dr. Roch (*Wasser und Abwasser*, Band 2, No. 3, 1909) does not go to show that this process is reliable from a bacteriological point of view, though there can be

little doubt that the chemical work done in the soil is very important, and the nitrification often complete.

The decomposition of organic matter is due in part to the vegetable and animal life in the slimy film which covers the sand. Algæ and diatoms, and all the forms of plankton occurring in the raw water, collect in the film, and pursue an active life among the sediment, drawing some portion of their nourishment from dissolved matters in the water. Bacteria swarm in myriads, and the saprophytic species live and multiply by the disintegration of organic substances. The indefatigable activity of bacteria replenishes the store of food on which the algæ thrive, and organic matters are, as it were, prepared for their consumption. Plant and animal débris alike come within the scope of bacterial operation. When the algæ die, their filaments are invaded by micro-organisms, and transformed into food for future crops of the same kind. Bacteria are indeed the handmaids of the more highly organized plants, and a necessary link in the biological chain. Just as a crop of land plants with the aid of soil bacteria exhausts the organic matters of the ground, and leaves very little in the drainage water save dissolved minerals, so do the plants of the filter-bed with co-operation of bacteria break down the same substances and purify chemically the water which passes through.

Action of Non-Submerged Filters on Sewage.—It is not, however, in the topmost layer alone that organic matter is acted upon. The investigations which have been made with regard to the purification of sewage by contact beds have served to throw much light upon the biochemical action which goes on in the deeper layers. If sewage be discharged upon clean sand, no reduction of the dissolved organic matter takes place at first (Dunbar, "Principles of Sewage Treatment," p. 138). Some days must elapse before the "oxygen consumed" declines by 50 per cent., the filter being meantime worked intermittently. Time is required for the granules to clothe themselves in the slimy coating which acts as a purifying agent. The filter-bed is considered to be "mature" when nitrates begin to show in the effluent.

The astonishing thing about the mature filter is the rapidity with which it does its work. Dunbar has shown that, if a volume

of sewage be poured over a filter still retaining the dregs of a previous charge, the newly added liquid does not force out the liquid already adherent to the sand, but passes through without displacing it. Further, it has been proved that sewage is completely purified and rendered non-putrescible in ten minutes by passing through a mature filter-bed 3 feet thick. Purification can be obtained, though possibly not so thoroughly, with much thinner beds, and in correspondingly shorter intervals, as, for example, in half a minute with a 9-inch filter.

Formerly the idea prevailed among bacteriologists that the purification of sewage in filters was due to the action of micro-organisms, a conception which would be quite reasonable if the process occupied two or three days. But the rapid elimination of organic matter noticed by Dunbar is beyond the power of bacteria. Hence the inference that the dissolved organic substances are withdrawn from the liquid as it percolates, are retained in the filter, and are decomposed by bacteria in a subsequent period of rest (Dunbar, "Principles of Sewage Treatment," p. 140). It is clear that the separation of dissolved organic matter cannot be a mechanical effect depending upon the minuteness of the pores, seeing that solutions of albuminoids pass unchanged through filter-paper and unglazed porcelain which intercepts bacteria. Nor is it the outcome of chemical changes; for if chemical reactions do occur, they are limited to certain favourable coincidences, such as the encounter of any iron salts in the filtering material with sulphuretted hydrogen, and the chance concurrence of ammonia with this same compound of sulphur. But such reactions account for very little of the whole change, and it is difficult to conceive of any possible chemical action as occurring in the filter that would explain the disappearance of albuminoid bodies in solution.

The Theory of Absorption.—Hence it was that Dunbar* put forward his theory of absorption. The absorptive agency is the gelatinous slimy film which covers each granule in the mature filter. At first this film is thin, but it gradually gains in thickness and in water-retaining capacity. Just as the gelatinous covering becomes thicker, so does the filter act more and more effectively on dissolved organic substances.

* "Principles of Sewage Treatment," p. 142.

The surface of the filmy coat is not an even and smooth one, but is corrugated and honeycombed, so that its external surface is enormously increased. In certain cases it appears that the surface is enlarged by such convolutions many thousand times. Besides its outer surface, the gelatinous film possesses an internal one, which probably has its own part to play. Such as it is, this slimy envelope has the power of absorbing gases with eagerness, and of withdrawing both organic and inorganic matters from solution. If, for example, the slime from a mature filter be washed into a bottle full of oxygen or carbonic acid, and the stopper with a manometer attached be replaced, there is seen to be a rapid diminution of the pressure, owing to the absorption of the contained gas. Solutions of albumin, or the peptone-like products of its decomposition, colouring substances, enzymes, tannins, and other things, are forced to part with more or less of the dissolved bodies. Strongly putrescible sewage, or a solution of peptone, when treated by a mature filter, becomes non-putrescible.

Examined with the microscope, the gelatinous film is observed to be full of micro-organisms, which live upon the absorbed matters and disintegrate them. They do this continuously in spraying and sprinkling filters, which permit of uninterrupted aeration, and with "contact" beds they work vigorously when the filter is emptied and the air permitted to enter. Experimentally it has been shown in the laboratory that much oxygen is absorbed and carbonic acid is exhaled. Oxygen is required for the vital processes at work, and as a final result the organic nitrogen appears in an oxidized state as nitrate. To exclude atmospheric oxygen or to sterilize the mature filter results in arresting the decomposition of the absorbed materials. The organic bodies are no longer mineralized.

Dunbar states that oxygen is not readily absorbed by a filter which is standing full of liquid, but that it is quickly taken up when the bed is drained, and just so much fluid left as can be retained by capillary action. He believes that there is a condensation of the oxygen molecules, so that ozone is formed in the gelatinous film which surrounds the granules. There is generally some proportion of iron in the composition of the slimy coating, which may lend assistance to the fixing of the oxygen. As throwing light on the action of iron, it may be stated that gravels containing large quantities of iron, show

marked power of absorption when sewage is poured upon them. Gravels of this kind abound in North Germany.

The purifying action of the film indicates the possession by it of a power quite outside the agencies previously familiar to science. It is not to be explained by surface attraction nor by dialysis. There is no reason to believe that surface attraction could withdraw dissolved matters from liquids in the way that the gelatinous film does. Dialysis is at best only a partial explanation, because non-dialysable substances (colloids), like albumin, are more readily absorbed than dialysable bodies. Dunbar considers the action of the film to be one of the nature of suction, and it has been variously named "*ad*sorption," "*re*sorption," or simply "absorption." It is this which makes the purification of sewage by natural means so simple, manageable, and economical. The range of substances over which the influence of resorption prevails is very wide. Not only are nitrogenous compounds, like albumin, peptone, and urea, withdrawn from solution, but sugar and saccharine bodies are removed from the effluents of sugar factories and other industries where these things go to waste.

The final outcome of a mature filter is the mineralization of the organic compounds, and a liquid is discharged which is non-putrescible. As has been already said, the nitrogen is discharged mostly as nitrate. Part escapes nitrification, and appears as ammonia, and there is a residue of organic nitrogen which is non-putrescible. About 60 per cent. of the total nitrogen in the crude liquid is converted into nitrate, 20 per cent. into ammonia, and the remainder is still combined with carbon in various ways. Sulphur of the crude liquid is oxidized to sulphuric acid. Much of the carbon separates out as carbonic acid, and the air over a biological filter operating on sewage has been shown to contain an excess of this gas. Pure water introduced into a mature filter carries out a considerable quantity of carbonic acid. The end products are nitrates, ammonia, sulphates, CO_2, some non-putrescible organic matter, and water. Such, then, are the ultimate products which issue from the biological filter, and such the transformations of molecular structure which it effects—from organic to inorganic, from putrescible to non-putrescible, and therefore to substances unfit to serve as food for the micro-organisms which flourish in decomposing matter.

Importance of Adsorption in Water Purification.—The bearing of the foregoing exposition of absorption and mineralization on the work of the sand-filter is of great interest. When the layer of sand has assumed its gelatinous coating, it is able to perform the de-solution of dissolved organic matter. In water which is intended for household use, the quantity of such is generally very small, so that the slimy film may go on for long periods actively sucking up organic matter, and doing some work in the way of mineralizing. Hence the decrease of albuminoid ammonia in the effluent, and the increase of oxidized nitrogen, which have already been commented on. In the biological filter for treating sewage, opportunity must be given for ample aeration, but this is less necessary when the crude water has but a minute content of putrescible substances. Possibly the oxygen dissolved in the water may suffice for the needs of the bacterial population. At any rate, the usual methods of working sand-filters do not make any provision in general for aeration. During cleaning it is now a common practice to let the water sink a few inches below the level of the sand, so that the free entry of air is precluded. With non-submerged filters, of the type devised by M. Baudet, the aeration is continuous, and the mineralizing process has full play.

It may be thought that too much has been made of the reduction of organic matter by filtration, and that no apprehension need be entertained about the hygienic state of service water which does contain minute amounts of putrescible substances. That is no doubt true, but it has to be remembered that filtered water is easily infected by chance contamination, and that bacteria introduced therein multiply with surprising rapidity. It may be assumed that the increase of germs is limited to a great extent by the amount of organic food available for their subsistence.

There are probably, as Frankland has pointed out, other circumstances to be taken into account, as the presence or absence of inhibiting matters, but we may reasonably assume that organic food is necessary to the saprophytes for their development. Therefore, the greater the scarcity of their natural food in filtered water, the less the risk of the bacteria accumulating, and the better the chance that, if they do happen to increase, they will speedily be reduced to normal conditions.

3. Bacterial Purification. — The retention of bacteria by the sand-filter has variously been credited to the skin of algæ and other living things which spread over the surface, to the gelatinous film which coats the sand and gravels, and to the combined effect of both of these agencies. The fine silt which gradually overspreads the top layer also plays a part in trapping germs, but it is not essential to good bacteriological results, seeing that these are often obtained when the raw water has little in suspension, as, for example, after lengthy storage. We know, however, that artificial films of alumina and iron oxide serve to exclude 99 per cent. of the micro-organisms, so that a share of the bacterial purification must be ascribed to the film of inanimate silt.

It is probable that both silt and sand act upon bacteria in the same way. The arrest of bacteria is due not so much to the minuteness of the interspaces as to the gelatinous coating which the particles assume. MM. Puech and Chabal have shown that an extensive capture of germs goes on in their roughing filters, in which the materials are of coarse grain, with the particles of the last compartment not smaller than peas. At Nantes the average reduction is from 10,000 germs per cm^3. to 4,000, a fall of 60 per cent. At Cherbourg the *dégrossisseurs* retain over 80 per cent. of the germs, and at Suresnes the average reduction from January to November, 1907, was over 90 per cent. (Trans. Assoc. of Water Engin., 1907, p. 328).

According to Dr. Kemna (Trans. Assoc. of Water Engin., 1907, p. 331), the diminution in the number of bacteria in the gravel strainers is independent of the speed of percolation. We have therefore to deal with an agency totally distinct from the artificial filter of paper, cotton-wool, or porcelain. Dr. Kemna explains that the bacteria are retained by a *sticking* or adhesive force (p. 86), which comes into play as soon as they come into contact with the surface of the pebbles. The gelatinous covering of these must be the main seat of that force, though no doubt the action is a mutual one between the film and the jelly-like bodies of the micro-organisms. At first, when the pebbles are clean, the bacteria are able to lodge upon them, colonies (*Zooglœa*) soon develop, and the characteristic slime is drawn over the whole surface.

The coarse sands and gravels of the prefilter in the Puech-

Chabal series still further reduce the bacterial content. From an average of 600 per cm^3., the number is brought down to 100. There is, of course, a filtering skin formed on the prefilters, which performs its part; but there is reason to believe that elimination of microbes proceeds in the deeper layers as well. As Pennink and others have shown, there are bacteria distributed right through the under-layers. In the finishing filter, which is composed of fine sand, no viscous film of vegetable growth is formed on the top, because the water arrives there free from spores or fragments that would initiate its growth. Yet the final stage of the Puech-Chabal process again reduces the number of microbes by about 60 per cent. At Suresnes the figures for the year 1907 were 100 from the prefilter, and 30 for the finished effluent of service water. As will be seen later, the authorities at the Amsterdam Waterworks do not set much store on the efficacy of the filtering skin.

Retention of Bacteria in Natural Beds of Sand.—The retention of bacteria in natural beds of sand and gravel is a well-established fact which accounts for the purity of underground sources of supply. Recently Drs. Ditthorn and Luerssen have made experiments to determine how far this natural elimination of germs may be depended upon to render sewage-polluted waters innocuous (*Gesundheits Ingenieur*, 1909, No. 41). Their tests were made in the neighbourhood of the boreholes at Tegel Lake and Müggelsee, from which the Berlin water is pumped. At Tegel the borehole chosen begins to admit water at a depth of 120 feet, and a wide tube 60 feet long, perforated below for a length of 3 feet, was sunk into the ground between the lake and the borehole, at a distance of 22 yards from the latter (Fig. 4). It was thus in the line of underground flow from the lake to the well. Between the lower end of the sunk tube and the well intervened layers of gravel and sand of varying fineness. Rich cultures of *B. prodigiosus* were then poured into this tube, and water was continuously run in so as to keep the level within from 3 to 5 feet higher than that of the ground water. The cultures were introduced at intervals of four days for a fortnight. After nine days the pumped water, which totalled 300,000 gallons daily, began to show signs of *B. prodigiosus*. On nine subsequent days at somewhat irregular intervals the tests gave positive results. The experimenters calculated that in all not more than 0·0025

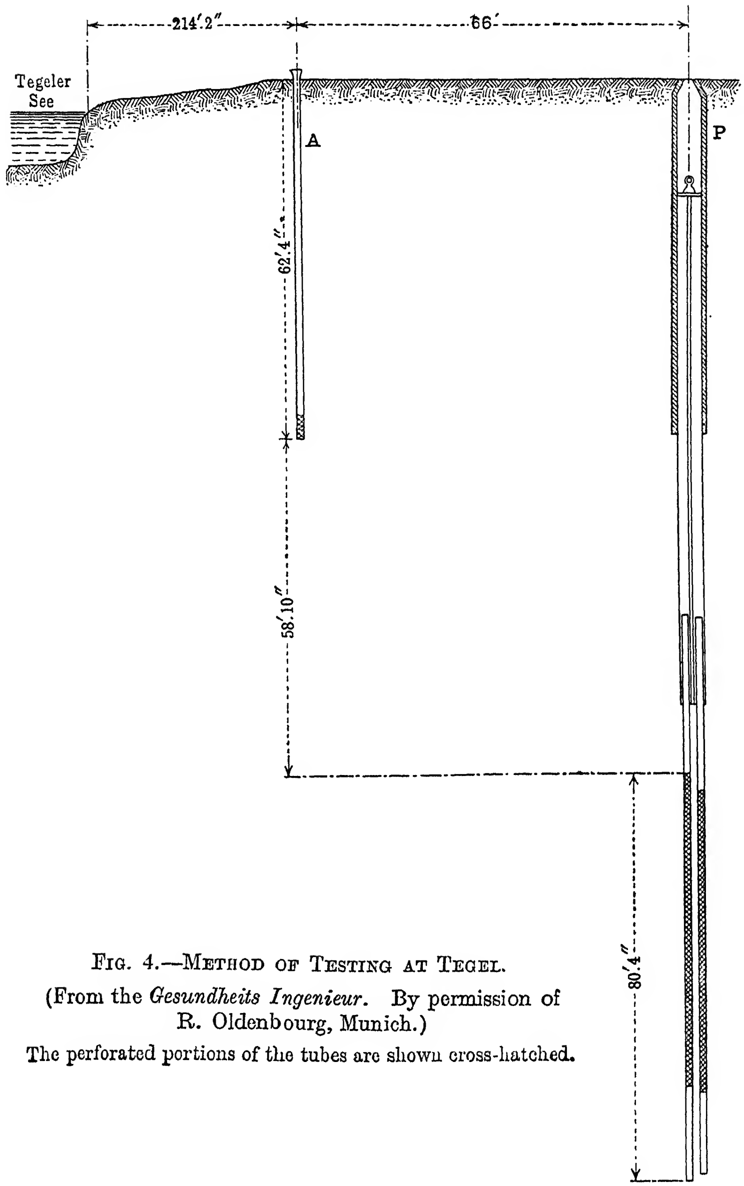


FIG. 4.—METHOD OF TESTING AT TEGEL.
(From the *Gesundheits Ingenieur*. By permission of R. Oldenbourg, Munich.)
The perforated portions of the tubes are shown cross-hatched.

per cent. of the germs poured into the tube had succeeded in reaching the well.

Similar experiments were then conducted at Müggelsee, but with a horizontal perforated pipe sunk in the ground to simulate a leaky sewer (Fig. 5). Layers of sand and gravel intervened between the tube and well, their total depth being about 70 feet. Tests were made from December, 1908, to February, 1908, and again from the latter date to the end of March with the horizontal tube put some 6 feet deeper. Large volumes of the pumped water were regularly tested, but on no occasion was *B. prodigiosus* discovered. Many thousand billions of bacteria had been poured into the horizontal tube, washed down into the gravels with water from a side-tube (*t*), but none percolated into the borehole.

It is thus manifest that deep layers of sand are almost perfect safeguards against the intrusion of bacteria, and the inference is that artificial filter-beds should not be too shallow. The authors found, by experimenting with a wide glass tube nearly filled with fine sand which had been kept moist for a fortnight, that no test bacteria (*B. violaceus* and *B. prodigiosus*) were able to pass through 8 feet of the sand. On gradually diminishing the depth of the filtering layer, by removing sand from below so as not to disturb the upper layers, it became possible to determine the retentive power of different thicknesses of the filtering material. The results are given in Table V.:

TABLE V.

Number of *B. Violaceus* per cm^3. in Crude Water.	Number of *B. Violaceus* in Filtered Water.	Depth of Sand.
100,000	Nil in 10 cm^3.	8 feet
100,000	Nil in 10 cm^3.	7 ,,
100,000	5 in 10 cm^3.	6 ,,
100,000	5 in 10 cm^3.	5 ,,
120,000	13 in 10 cm^3.	4 ,,
120,000	18 in 10 cm^3.	3 ,,
120,000	109 in 10 cm^3.	2 ,,
15,000	36 in 1 cm^3.	1½ ,,
1,000	27 in 1 cm^3.	1 foot

Number of Bacteria inhabiting the Under-Layers of Sand.—Fraenkl and Piefke in their research on sand-filters (*Zeit-*

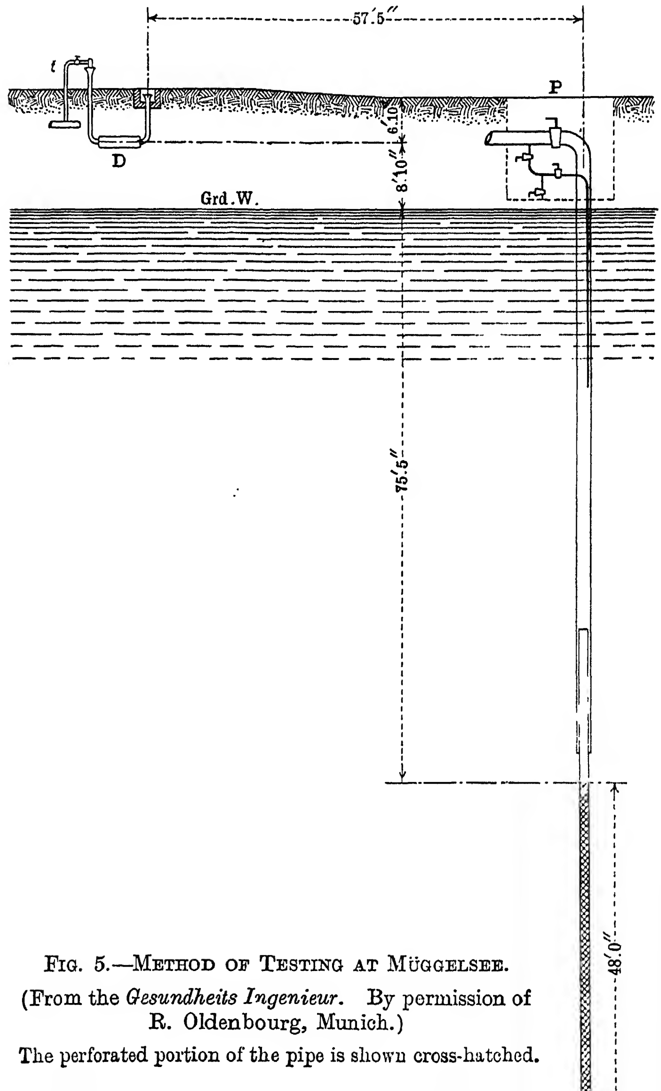


FIG. 5.—METHOD OF TESTING AT MÜGGELSEE.

(From the *Gesundheits Ingenieur*. By permission of R. Oldenbourg, Munich.)

The perforated portion of the pipe is shown cross-hatched.

schrift für Hygiene, vol. viii., 1890) found that the Berlin filters were inhabited by a rich flora of germs down to and including the layer of flints on which the sand rested. A pound of sand taken at the depth of 1 foot contained 40,000,000 of micro-organisms, approximately 180,000 per cm^3. of material. The flints contained about half as many, and the sand near the surface far more. As the Berlin filters were at the time producing a satisfactory effluent with only a moderate number of germs per cm^3., it follows that the sand was quite able to retain the immense host of bacteria that were lodged in it. We shall further refer to the manner in which they may be carried out of the bed when we deal with Pennink's views on sand-filtration.

Fraenkl and Piefke also proved that a filter-bed formed of clean and sterilized sand had *no* power of intercepting germs, and, as Dr. Frankland remarks ("Micro-Organisms in Water," p. 158), it is clearly demonstrated that it is the slime deposit on the sand which constitutes the real filtering material in the waterworks filter.

Non-submerged sand-filters must depend entirely on the efficacy of the slimy coating. Those installed at Châteaudun eliminate almost the whole assemblage of bacteria from the crude water (see p. 147). The Bedford sprinkling filters do their work without any film, and the only thing noticeable is that the sand is discoloured at the depth of a few inches below the surface. It is well known that biological filters do not entirely remove pathogenic germs from sewage, but neither do irrigation farms, on which there is always a surface film. Reductions of 99 per cent. and above are obtained at the intermittent filters in Massachusetts, and also at the Freiburg and Brunswick sewage farms, and generally, according to Dunbar ("Principles of Sewage Treatment," p. 233), the efficiency of these methods of sewage treatment, so far as concerns the removal of bacteria, is about equal.

From the foregoing considerations two conclusions may safely be drawn: The first, that micro-organisms can be removed from water by a sand-filter whether there is a surface film or not; the second, that the sand-bed does its work best when the granules have become coated with slime and gelatinous growths that swarm with germs.

Director J. M. Pennink (Amsterdam) on the Working of Sand-Filters.—The views expressed by Director Pennink of Amsterdam

in his article on the "Nature of Sand-Filtration" (*Journal für Gasbeleuchtung und Wasserversorgung*, No. 27, July, 1908) have attracted much attention on the Continent.

He is clearly of opinion that the ideas generally entertained with regard to the function of the filtering skin are erroneous. In the case of water purification, Pennink feels that theory has gone ahead of practice, and that, where unsatisfactory results are obtained from the sand-filter, the reason is to be found in the unscientific method of handling it. There are, according to this authority, grave misconceptions abroad with regard to the function of the sand-bed itself independently of the film of vegetable and animal growths. The latter, he does not hesitate to affirm, is more often a source of trouble and cause of inefficiency than any real help towards the elimination of pathogenic bacteria.

Efficiency of the Sand-Filters at Leiduin.—In proof of this he instances the working of the sand-filters at Amsterdam, which have consistently delivered an effluent which is practically sterile. Absolute freedom from bacteria is not claimed, but the germ content is so small that the water may safely be classed as among the very purest that can be got from any of the most modern appliances. Table VI. indicates the results obtained at the Amsterdam Waterworks for months on end. The figures given are to be taken as showing the usual efficiency:

TABLE VI.

	Colonies per Cm³.	Number of Liquefying Colonies.
Unfiltered water	1,950	210
Primary filter	250	40
Secondary filter	11	3

DETAILS OF VARIOUS SECONDARY FILTERS.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Number of days in use ..	2	8	11	31	84	18
Pressure difference in centimetres	5	19	19	41	59	41
Total number of colonies ..	3	2	11	4	8	6
Number of liquefying colonies	1	0	3	0	2	0

The primary filter referred to here was composed entirely of a gravel with grains ranging from $\frac{1}{25}$ to $\frac{1}{3}$ inch in diameter. The speed of the water passing through it was about 80 inches per hour. The secondary filter, on the other hand, consisted of dune sand of very fine grain, of the same grade from top to bottom.

Importance of Uniform Speed of Filtration.—The greatest care is taken in the management of these filters, and the plan of construction and the method of working are based on the scientific knowledge obtained from investigation of the mechanical and biological phenomena of the sand-filter itself.

Unsatisfactory working is due to one or other of many causes. Good filtration is closely dependent upon the strict

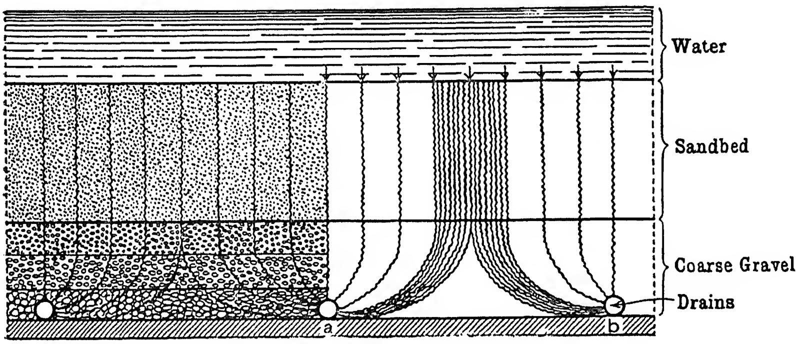


FIG. 6.—SECTION OF ORDINARY SAND-FILTER.
(By permission of Director J. M. K. Pennink.)

regularity of the operation of the sand-bed. Regulators are indispensable, but even when these are in use the bacteriological results are not infrequently unsatisfactory. Pennink goes on to explain how this comes about.

The diagram (Fig. 6) represents an elevation of an ordinary filter in section, with gravels below, and drainpipes (*a*, *b*) at intervals along the bottom. Owing to the fineness of the sand in the top layer, there is here greater resistance to percolation, and the water on reaching the gravels proceeds on its way to the drains somewhat after the fashion represented by the wavy lines in the figure. Consequently there exists between each pair of drainpipes a region in which there is but little flow. This is represented in the diagram by the triangular

space above *a*, *b*, and such regions of retarded flow are more in evidence when the bottom of the filter-bed is flat or nearly so.

Bacteria carried out of the Sand-Bed by Irregular Flow.—The researches of Piefke, Reinsch, and others, have shown that the whole depth of the sand and gravel is tenanted by bacteria, and that, while the number of these is greatest in the upper layer of finer material, it is often very large in the underlying bed of coarser granules. The natural inference from this circumstance is that the layer of fine sand should form as great a proportion as possible of the whole, and that the gravels should be reduced to quite a thin stratum, or, indeed, should be entirely dispensed with. The immediate cause of the increase of germs in the coarse layer of gravel is the existence of the above-mentioned regions of feeble movement. Every variation of the direction and course of the stream lines in the gravels, which invades a region of impeded flow, carries away a portion of the bacteria which pullulate therein. In this way Pennink accounts for occasional and well-marked variations in the bacterial content of the filtrate in ordinary filter-beds.

How a Uniform Rate of Flow may be secured.—The obvious remedy has been already indicated, and an additional security is gained by so constructing the bottom of the filter that uniformity of flow is better assured. He recommends that a the bottom of the filter-bed should be undulating in section with the drainpipes running along the valleys. So soon as the water has passed out of the layer of fine sand, its stay in the filter should be abbreviated as much as possible. Hence broad channels for draining away the underflow are to be avoided, because the semi-stagnant condition encourages the growth of bacteria. Nor, according to Pennink, are air canals an advantage, for they lead to an increase in the number of germs, and the sand-bed does not stand in need of aeration.

Loss of head in the sand-filter arises from two causes :

1. There is the frictional resistance of the tortuous passages between the particles of sand and gravel, together with the less important friction in the drains and outgoing conduits.

2. The formation of a surface film of slime, algæ, desmids, etc., occasions a gradually increasing resistance.

Inconveniences arising from the Filtering Skin.—Now, the maximum head of water permitted at various stations ranges from 20 to 40 inches, corresponding to a pressure of from 100 to 200 pounds per square foot. Complete uniformity of the film is not to be presupposed, and so it happens that percolation goes on more easily at one part than at another. Most likely after a time the film becomes almost impermeable here and there, while, again, there may chance to be breaks and holes at various places. Whenever, owing to irregularities in the film, the water can penetrate with increased rapidity, there, without doubt, germs will be drawn along. Towards the end of a run, the filtering skin becomes so thick and so compacted with the augmented weight of water that it is almost air-tight, and when the water is lowered preliminary to cleaning there may be left a partial vacuum under the top skin. Should that occur, the pressure of the air would force a passage, and drive millions of germs into the body of the sand. Pennink thinks there is little doubt that at every cleaning impurities are sucked down into the sand. The ingress of filtered water from below after paring only serves to distribute the foul matter throughout the layers.

The air which makes its entrance into the bed during cleaning has the reverse of a beneficial effect, for it becomes entangled, but not uniformly, all over, and lessens the permeability of the sand at places, and thus destroys the even working of the bed.

At Leiduin Waterworks the filter-gauges are self-registering, and these clearly demonstrate the fact that the velocity of percolation increases and diminishes alternately. The line traced by the gauge is an undulating one, with as many as eight maxima per minute, when the rate of filtration is low. But as the speed increases, so do the differences between the maxima and minima become more and more pronounced. With the water passing downwards at the rate of 3 feet per hour, these variations of speed amount to no less than 10 per cent. of the average rate. High speed of filtration is therefore unfavourable to regularity.

Variations in the temperature of the crude water also lead to change in the rate of drainage through the sand. Allen Hazen supplies a formula which is applicable here, and he concludes that for every degree Centigrade the temperature

rises over 10° C. the rate of percolation increases by 3 per cent. If the temperature falls, the rate diminishes by an equal percentage.

Advantages of using Sand of Fine Grade.—Let us now follow for a little the incidents that accompany the passage of water through sand of fine grain, such as is in use at Leiduin. Here the average diameter of the granules is $\frac{1}{100}$ inch, and one half of the whole is under $\frac{1}{125}$ inch, so that the pores or interstices may be taken as 35 per cent. of the whole volume. Sand of this fineness takes up one-fourth of its volume of water. Each cubic yard of this sand contains 35,000 to 40,000 million particles, whose united surfaces would, if spread out, cover an area of many thousand square feet (see p. 99). Over this extensive surface the water which enters each square yard of the filter (whose depth is taken at 3 feet) must be spread; so that if we know the volume delivered by a square yard per hour. it becomes possible to calculate the thickness of the film of water which slips over the particles of sand. If the rate be 4 inches per hour, for example, so that a volume of 3 cubic feet flows from each square yard per hour, the thickness is almost inconceivably minute, being only about $\frac{1}{5000}$ inch. In reality it is not so much, for the surface of the grains of sand is enlarged by the thin coating of moisture which clings to them by capillary attraction.

Nor is this covering to be regarded as pure water, but rather a composition of organic and inorganic, somewhat slimy, matter which clings adhesively to the granules. Thus the microscopic intervals between the sand particles are still further diminished, so that the actual thickness of the lamina of percolating water may not be more than $\frac{1}{10000}$ inch. Little wonder, then, that a good working sand-filter of this description frequently has been found to deliver sterile water.

The Slimy Coating of the Sand Particles captures Bacteria.—Representing now, as in Fig. 7, a single particle of sand by the circle S, and its thin jacketing of slimy fluid as bounded by the outer circle, it is known that any droplet of water which comes into contact with the film will tend to fuse and amalgamate with the liquid surrounding the sand. Should the water which is thus added to the original covering of the particle carry any minute impurity, as a germ, for example, this will

also be drawn into the film. Such an occurrence is represented as taking place in the figure, where the watery envelope surrounding a minute particle (represented diagrammatically by the small starred circle at the top) is shown in the act of coalescing with the outer film of the sand granule.

Once imprisoned within the skin of fluid which covers a particle, the tiny germ will have difficulty in escaping. It will probably adhere to the sand or to the slimy particles within the film. But it will have opportunities of quitting its confinement, because water is constantly being added to the film, and as constantly being withdrawn as the current moves downwards. From all experiences, it would appear that, if the rate of filtration is kept constant, the germs do prefer to rest within the filmy coatings of the sand-grains. But any change in the speed of percolation tends to carry them away. A little consideration of the phenomena as they actually exist in the sand-bed will make the cause of this more clear.

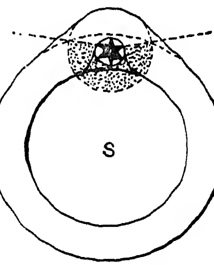


FIG. 7.—WATERY ENVELOPES OF SMALL PARTICLE AND OF SAND GRANULE UNITING. (After J. M. K. Pennink.)

As a matter of fact, the sharply-defined film represented above as surrounding each particle does not have the opportunity of separating itself as a distinct thing from the general mass of water within the sand. But we may regard the adhesive attraction exercised by the solid particle upon the adjacent liquid as having a range of action which is bounded by such a limit as is indicated by the outer circle in the figure. The power of the sand-grains over fluids and moist, jelly-like particles extends to a minute distance outwards, but within that zone it restrains the free movement of the surrounding liquid, and of whatever may be carried with it. Into this zone from above is continually passing fresh liquid, owing, of course, to the downward movement in the filter, and out of it is also departing an equal amount from below. There is a play of forces between the adhesion of the sand, the cohesion of the particles of water, and the gravitational pull downwards. The resultant under normal working will be a steady flow upon the boundary of the zone of influence of the sand-particle. This current will not disturb particles lying close to the sand and well

within its zone of attraction. Embracing each grain of sand there is thus a region of quiet into which the suspended particles and bacteria gather, just as they do in the still places of a water course. But any acceleration of the current, any disturbance which throws the water into agitation, stirs up the particles already deposited, withdraws them from the influence which has been restraining them, and bears them along in the direction of the general flow.

Pennink's hypothesis regarding the function of the sand would seem to require us to picture each granule as retaining its watery jacket distinct from the general mass of liquid in the sand-bed. Doubtless, when the natural drainage removes all the "free" water from a particular spot, each grain of sand retains firmly its own moist covering. The smaller the granules, the more tenaciously does the capillary film bind itself to the kernel, retaining the minute germs and other microscopic particles that may be within its grasp. Pennink thinks that microbes of dimensions averaging about $\frac{1}{50000}$ inch in diameter may easily be arrested in this manner.

Aeration of the Sand-Bed.—No useful purpose is served, according to Pennink, by draining off the water from the sand-bed at cleaning, on the plea of aerating the layers. By drying, the covering of the sand-grains is destroyed, and time is required to bring about the state best adapted for intercepting bacteria. "As has been remarked," says Pennink, "dirty sand filters much better as a rule than clean sand." Hence he does not approve of washing the dune sand before placing it on the filters. Washing would be certain to carry off much of the finest particles. It might also destroy the slimy coating with which the granules may happen to be surrounded.

The filtering skin has long been considered to be the effective medium in the process of sand-purification. Pennink sees but few advantages connected with it, and, on the other hand, several pronounced disadvantages. We are to bear in mind that all irregularities in the flow of water within the sand-bed are detrimental. Disturbances in the covering film immediately lead to variations in the rate of flow, and there are many things which are prejudicial to the continuity of the film. Sunlight sets free from the algoid filaments numerous bubbles of oxygen, which break through the network and leave

tiny gaps and tears. The larvæ of Chironomus (Fig. 8) are often found in the top layer of the sand, and at many waterworks they flourish in vast numbers. In creeping upwards, they perforate the filmy covering and leave small holes. Often it happens that large pieces of the algoid growths rise from the sand, buoyed up by the gases disengaged in the course of their growth. They tear away and slacken neighbouring areas of the covering. Patches of the surface are thus left bare of any algoid covering, and the water passes without hindrance into the deeper layers. The uniformity of speed within the body of the sand is at an end.

The experience of water engineers who have to deal with profuse growths of algæ will probably lead them to agree with Pennink in regard to the disadvantages of the filtering skin. To the water manager the most vital point is the relation of the algoid film to the life of the filter, and he knows that under certain conditions it soon becomes inconveniently dense, and sets a limit to economical working. He understands that good bacteriological results are not as a rule obtained until the sand is sufficiently filmed. But it is not to be forgotten that, while the algoid growths are constructing the overlying skin, the sand-grains immediately underneath are also acquiring that slimy coating which, as we have seen, can accomplish so much in the way of bacteriological purification. During that considerable portion of the year when algæ cease their growth, the filter must pursue its operation with either no film or with a covering of a very different character from that with which it is provided at other seasons. Then, it must be admitted that, if equally good bacteriological results are obtained, the efficiency cannot be credited to the film alone. And, as we have seen, as good results have been obtained at Amsterdam with no film as with a thick coating of algæ. At Bedford the raw water, partly purified by mechanical filtration, is distributed over the sand by means of sprinklers, and it sinks immediately into the bed. No filming is possible. Yet the purification is quite equal to that which might be expected from the ordinary type of slow sand-filter. In the

FIG. 8.—CHIRONOMUS (LARVA). (× 10.)

Bedford filters it is noticed that the sand, which is brought from Leighton Buzzard, retains its natural whiteness to the depth of an inch or thereby, but it becomes discoloured deeper down. We may presume that the water-level in the bed approaches close to the surface, and that just under that level the activity of the slimy coating of the grains is most active. The sand removed from the sprinkler beds on cleaning contains a brown mat of interlacing fibres, which can be detached from the sand-heap in large patches. Covered filters have been constructed with good results at various places (p. 61). These considerations must modify the views often expressed regarding the paramount importance of the filtering skin. Its rôle is an important one, without doubt, and very frequently it performs a large share of the bacteriological purification. But it is not indispensable. The functions performed by it, or at least attributed to it, can be carried on by the sand-granules. The bacteria are retained in their adhesive coating, and under the best arrangements comparatively few escape with the filtrate.

Rate of Filtration in Relation to Efficiency.—There is some divergence of opinion as to the influence of speed on the efficiency of filtration. Dealing with the Puech-Chabal strainers, Dr. Kemna argues in a very convincing way that the elimination of microbes should be independent of the rate of the current, and this is found experimentally to be near the truth. When a tiny particle collides with a slime-covered grain of sand or gravel, it experiences a retaining or sticking force. But the momentum of the moving particle will tend to overcome the attraction between itself and the slimy film. This momentum is expressed by the product of the mass of the moving body multiplied by its velocity (MV). With bacteria and other very light specks of matter, the product MV may be almost infinitesimally small even with high rates of filtration. With such the *sticking* force prevails, while heavier particles are borne along in the current.

In sand-filters the speed is reduced very much at the commencement of a run after cleaning, and gradually increased up to about 4 inches (10 centimetres) per hour—that is, an output of water equal to rather more than 2,000,000 gallons per acre per day. MM. Puech and Chabal allow their finishing filters to

work at higher rates than this. At Antwerp the finishing filters work at rates of 2, 3, 4, etc., up to 10 centimetres per hour, according to their age and the quality of the effluent. Fraenkl and Piefke experimented with two filters, one working at 4 inches per hour, the other at three times that speed (*Zeitschrift für Hygiene,* vol. viii., 1890). Test bacteria were introduced, and the numbers that passed the two filters counted. The result was greatly in favour of the slower rate of working.

Again, when the slow filter was made to work at 2 inches per hour, the contrast was still greater. The following are some of the results :

TABLE VII.

Crude Water.	Number of Bacteria in the Raw Water.	Rapid Filter.		Slow Filter.	
		Rate of Filtration.	Number of Bacteria in Effluent per cm³.	Rate of Filtration.	Number of Bacteria in Effluent per cm³.
Berlin service water	Very large number of *B. violaceus* introduced	12 inches per hour	177*	4 inches per hour	93
Raw Spree water	Innumerable naturally present, and many *B. violaceus* added	As above	185†	2 inches per hour	72†
Spree water	As above	As above	390†	As above	118†

In these tests with the Spree water, it is to be remarked that the quick filter clogged after eight days, and the comparison made here refers only to results got during the last four days of a run. The slow filter ran for a month without cleaning.

Thus we see that with four days' ripening the quick filter was far surpassed by the other. But on one occasion the quick filter operated for twelve days, and on the ninth, eleventh, and twelfth days it actually intercepted more micro-organisms than the slow one did, the latter having been in action for three weeks, and only delivering a sixth of the volume of filtrate. The averages for the two filters for the ninth to twelfth days of that period are 87 for the quick, and 91 for

* Filters had been in operation for eight days.

† Average of four days after filters had been put in service.

the slow. At this time the head of water in both was about the same—namely, 3 feet—so that the slow filter was more clogged than the other.

A slow rate of percolation is a factor in the efficiency of a sand-filter. It is one that has great influence in a bed newly started after cleaning, but after it has been at work for a few days the efficiency becomes less and less dependent on the speed. It is unwise and unsafe to demand more than a small fraction of its normal output from a freshly pared filter, though

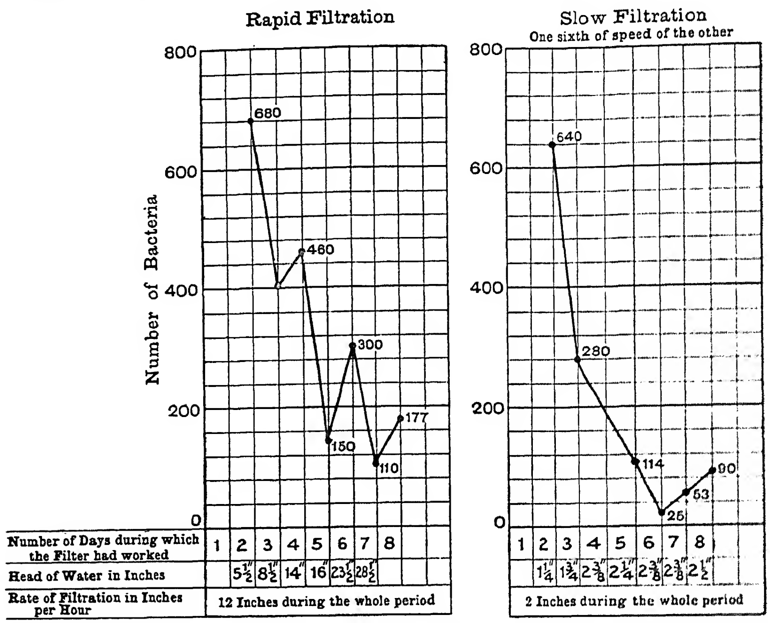


FIG. 9.—NUMBER OF BACTERIA IN RELATION TO RATE OF FILTRATION.

there is often a temptation to do so. Dr. Kemna begins with two-tenths on the second day, and increases gradually to the full rate, taking care to note by bacteriological tests whether an increase may be safely ventured. We notice in his reports a rate of three-tenths of the maximum (4 inches per hour) on the fifth and sixth days, half-speed on the thirteenth, and so on. Fraenkl and Piefke found that the slow filter did not work satisfactorily on the second or third days, even though the sand used was taken from a filter-bed actually in use, and was initially well coated with slime. The results obtained by these

rimenters are graphed in Fig. 9, and alongside is shown 10) in the same fashion the beneficial effect of working rst with low rates of output. The data for this were ned by the authors with a sand-filter.

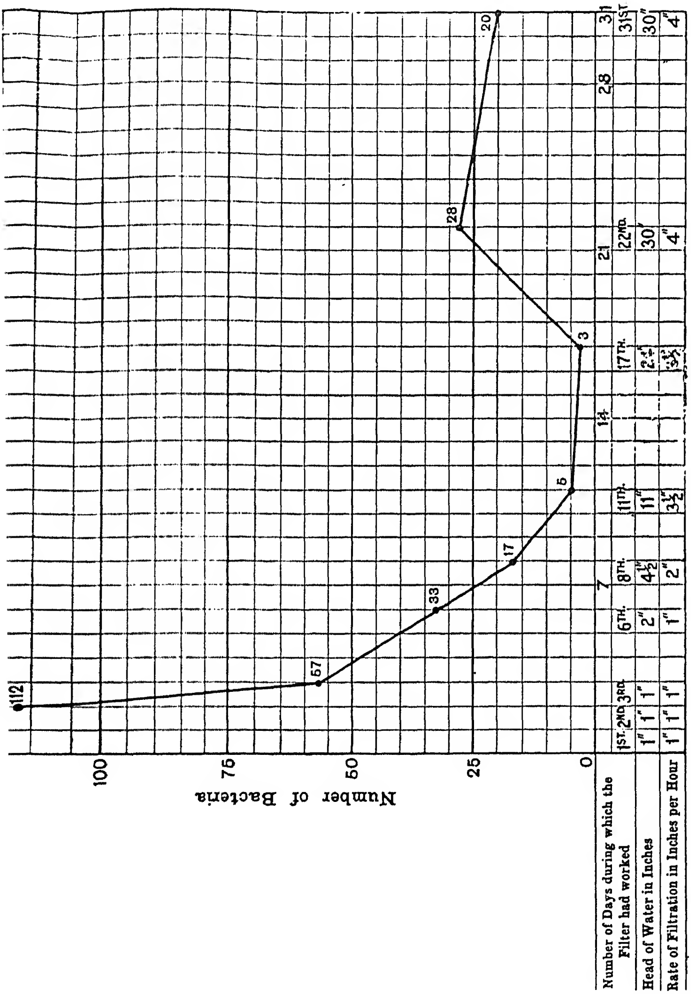


FIG. 10.—GRAPH SHOWING ADVANTAGE OF FILTERING AT A SLOW RATE. WHICH IS GRADUALLY INCREASED.

getable and Animal Growths of the Filtering Skin.—We now consider briefly the nature of the film which is formed e surface of sand-filters. Putting aside fine silt and mud, lm is chiefly composed of vegetable growths of a lowly

type, among which diatoms, green algæ (Fig. 11) and blue algæ (Fig. 12), innumerable bacteria, occasional fungi, and

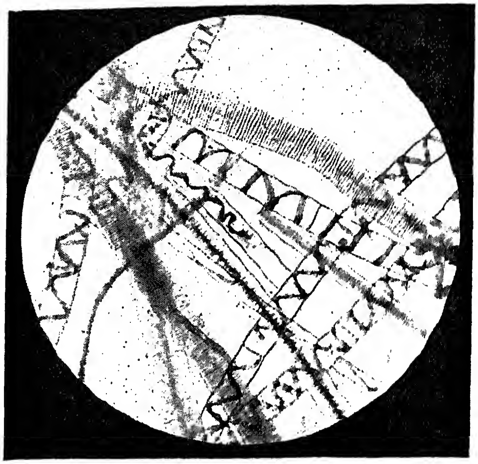


FIG. 11.—SPIROGYRA (GREEN ALGA) AND FRAGILARIA. (× 125.)
(From a photo taken by Mr. Walter Clemence, M.I. Mech. E.).

a few other species, are most noticeable. Provided that the raw water carries with it the matters necessary for "sowing" the bed with these types, the top layer of sand is soon

FIG. 12.—ANABŒNA (BLUE ALGA). (× 400.)

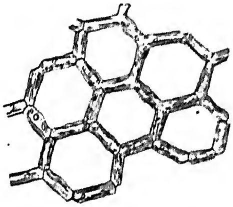


FIG. 13.—HYDRODICTYON. (× 175.)

pervaded by an active propagation, which in the course of a few days will have formed a continuous, though not necessarily uniform, web of interlacing fibres.

Bacteria abound, and they often exhibit coherent masses which attach themselves to the filaments. These jelly-like bodies, or zooglœa (Fig. 14), are defined by Whipple as aggregations of bacteria within a glutinous matrix, more or less transparent. There are also other slimy flocks of a brownish colour, which do not contain micro-organisms as a rule, and

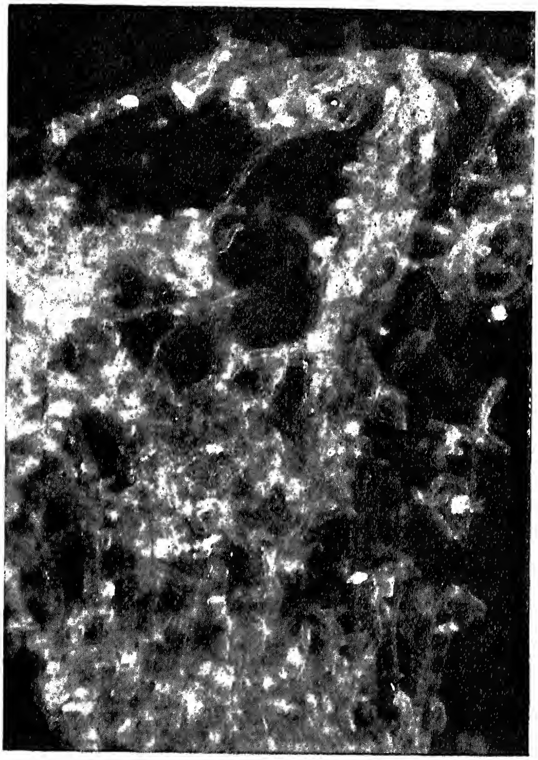


FIG. 14.—ZOOGLŒA.
(From a photo lent by Mr. F. P. Candy, London.)

are looked upon as the results of putrefactive changes. Abundantly distributed over the living network are the diatoms, slimy by nature from the fact that their outer walls secrete a gelatinous fluid. The filaments of algæ often appear under the miscrocope to be glutinous and viscid externally, a condition which seems to be characteristic of the older filaments. Floating plants and animals (plankton) sink

to the bottom, and add their numbers to the abounding variety.

While co-operating with each other in the destruction of water-borne impurities, the different forms of life in the filtering skin are at war with each other. Green algæ are destructive to microbes, and, according to Dr. Strohmeyer of Hamburg, a healthy growth of algæ may under favourable conditions sterilize the surrounding water in the course of one day. Many kinds of plankton also feed on bacteria. Direct sunlight is destructive to them—partly, no doubt, because it accelerates the liberation of oxygen from living plants. By the adhesive force brought to bear on bacteria in virtue of the viscid superficies of algæ, diatoms, etc., by the slimy coating of the sand and silt, these minute organisms are prevented from moving onwards with the current. Their own soft, viscous nature assists the sticking force. On the whole, the surface film contains the elements of an effective bacteria trap, and there can be no question of its usefulness under normal conditions. It is not, as we have tried to show, the only agency in the sand-filter by which micro-organisms are eliminated, and there are certain inconveniences inseparable from the growth of surface films that have been already referred to.

The more commonly occurring types of algæ which are met with in sand-filters are shown in Figs. 11, 12, 89, while the characteristic diatoms are described under Plankton (Fig. 88).

Seasonal Changes in the Composition of the Filtering Skin.—The composition of the filtering skin varies much with the season of the year. The green algæ are hardly to be found in winter, but they wake up in spring and grow vigorously throughout the summer, and diminish again in autumn. Blue algæ are most prominent in the hotter months, and are absent in winter. Diatoms, on the other hand, flourish throughout the year, though the same type does not prevail all the time. Dr. Zacharias states that the diatom Melosira (Fig. 88, *e*) develops rapidly between December and April, and then decreases; while Fragilaria has a corresponding period of vigorous growth between May and the end of summer. Drs. Kemna and Van Heurck took pains to count the species frequenting the Antwerp filters, and the former (Trans. Assoc. Water Eng.,

1899) states that 90 per cent. of the whole surface pellicle there in April was composed of two diatoms—viz., Melosira and Fragilaria (Figs. 11, 88, *c*) The remainder was made up of green algæ, chiefly Spirogyra (Fig. 11), and some other forms in comparatively small numbers. Very few blue algæ were noted, and only an occasional member of allied species.

Later on in the year blue and green algæ became the dominant types, and concurrently new species of diatoms began to appear, and in particular Synedra (Fig. 88, *f*, *g*). The surface pellicle had now become much thicker, and possessed a certain toughness and coherence, so that patches could easily be peeled away. In the earlier part of the year this could not have been done; in fact, it was difficult to scrape off the pellicle at all without bringing the sand along with it.

The green algæ of the class Hydrodictyon (Fig. 13) often contribute to form a rich felting of vegetable matter, its pentagonal meshes serving to bind the fabric together.

Influence of Changes of Growth in the Film upon the Filtrate.—It might be expected that the abundance of growth in the warmer part of the year, in comparison with the scanty crop of the winter, would make the results of filtration far better in the one season than in the other. This is not, however, true to any great extent. Dr. Kemna has expressed the opinion that diatoms play a very important rôle in the elimination of germs, and he even goes the length of calling them the true filtering agency, so far as that may be the function of the surface film. Efficient work is done at many installations during the whole year, and occasional bad results do not appear to be more common, so far as bacteriological returns are available, in winter than in summer. The confidence which was formerly entertained with regard to the efficacy of the filtering skin has not been gaining ground in recent years.

Liberation of Oxygen from Algæ, and its Consequences.—The liberation of oxygen from the submerged plants in the film increases the buoyancy of the filaments, so that they strain upwards somewhat. In this condition Dr. Strohmeyer considers that they operate with the best effect, their branching threads gathering the fine silt and capturing bacteria, while generally keeping the whole in a spongy and porous consistency,

so that the water percolates easily. But if the evolution of gas is too rapid and impetuous, the network of algæ is detached from the sand, rupture takes place, and portions mount to the surface. There is thereby produced a state of affairs that is certain to give a filtrate of questionable purity. The resistance is lessened at places laid bare by the breaking away of the algoid skin, and more water passes there. The increased flow escapes treatment by the film, and, descending with accelerated speed, it causes disturbance in the flow already established in the sand-bed, and thus brings about a state of matters in which the bacteria lodged in the sand are most readily detached and carried away into the effluent (see Director Pennink's views, p. 79). Dr. Kemna states, from his experience, that the number of microbes in the filtered water increases greatly whenever ruptures occur in the filtering skin, and he advises water managers to be on the outlook for such accidents, and to reduce the rate of filtration when the fault is observed.

Films formed during a Quick Growth of Algæ.—Algæ often grow so rapidly and in such compact masses that the head of water must be steadily raised to maintain the output, and the life of the filter is materially shortened. Luxuriant growth of new filaments is accompanied by the decay and death of older ones, which are overgrown and smothered, so that the filtering skin becomes a depot of decaying vegetable matter. Decay on an extensive scale affects the colour, taste, and odour, of the water. Green algæ are less objectionable in this respect than blue. Of the latter, Anabœna (Fig. 12) has a grassy odour in life, which becomes intensified and mouldy in character when it dies. This is believed to be due to the setting free of globules of a disagreeably-smelling oil when decomposition supervenes. Many of the species that vegetate in the sand-filter produce oils in the course of their growth, but not all these oils are offensive. The diatom Melosira, already mentioned, if present in considerable numbers gives the water an oily flavour without distinctive smell. Asterionella (Fig. 88, *a*) and Volvox (Fig. 86, *f*) have a fishy smell, as have the allied forms Eudorina (Fig. 86, *e*) and Pandorina.

Odours arising from Decaying Algæ.—As the blue algæ decompose, the oils and pigment rise to the surface, and a nauseating

scum overspreads the surface, the smell being perceptible at a considerable distance. Whipple avers that all the odours given off by the decomposition of microscopic organisms are offensive. The well-known fungus Beggiatoa (Fig. 15), which forms whitish-grey patches in certain waters, has an odour of sulphuretted hydrogen. Jackson and Ellms (*Technical Quarterly*, 1897) state that organisms containing a high percentage of nitrogen yield the most nauseating smells when they break up. Dr. Kemna remarks on the notable deterioration of the water in one filter-bed after treatment with copper sulphate.

The trouble which arises from bad odours is, fortunately, only an occasional incident of the warmer months of the year, and it is in general within the power of the water manager to take precautions against it in time. When the reservoirs are seen to be overcrowded with plankton and other low forms of aquatic organisms, it is advisable to seek a remedy (see pp. 44-47). It is against economy, also, to allow prolific growths in the filter, thereby abbreviating its period of work, increasing the cost of management, and introducing risks of rupture in the film which lead to unsatisfactory results.

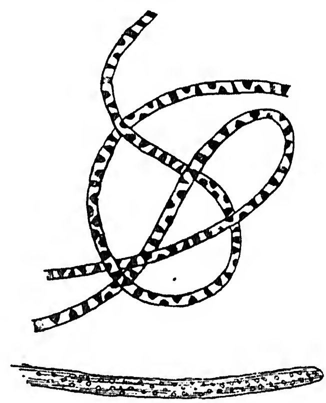


FIG. 15.—BEGGIATOA (FUNGUS). (× 500.)

Importance of a Uniform Film; Breaks due to Insect Larvæ.—Continuity and closeness of fabric must be looked upon as essential to the serviceableness of the filtering skin; for whenever breaks or perforations occur to any great extent, it becomes a hindrance rather than a help to good purification. In waters pullulating with living organisms it is little wonder if the surface film is at times disturbed by their activities, seeing that so many insect larvæ and other creatures accomplish a stage of their development in the superficial layers at the water bottom. Dr. Kemna specially mentions in this regard the evil consequences of the presence of the blood-worm, which burrows in the sand, and forms a tubular test for itself by

cementing together particles of sand. They are sometimes so abundant that the top layer of sand appears to be flecked as with worm-casts dispersed broadcast. While the worm rests in the tube no harm arises, but presently it completes a metamorphosis, and issues from its test as a fully-developed insect, the so-called Chironomus (Fig. 8). This winged, gnatlike creature rises to the surface and to the air, and it is interesting to note that its appearance does not escape the notice of the swallows, which ply their pursuits with great activity when the insects are coming up fast. The tubes deserted in the sand now become ready conduits for the escape of water, the uniformity of flow in the sand-bed is disturbed, and, according to Kemna, the bacterial content of the filtrate increases. The same authority reminds water managers not to neglect the obvious meaning of the visits of swallows to the filter-basins, so as to be ready to take steps to limit the output or clean the filter.

In summer it is rare to miss these red worms in the green slime raked from the sand, and at the Amsterdam works one of the authors noticed hundreds of them in every handful. Chironomus lays its ova in a glutinous thread, and often these delicate filaments may be seen in great numbers attached to the sides of the bed, just where they are lapped by the water. This points to the desirability of keeping these parts clean, so as to prevent a future crop of worm pests. Chironomus is the cause of greatest harm to the filtering film, but other creatures occasionally break up the surface. The "water boatman," an active aquatic insect, makes a practice of diving to the bottom, seizing particles of sediment, and carrying them upwards to search for food. Dr. Kemna does not consider that these insects do much harm, though they stir up a deal of mud. He also mentions having had trouble with eels and sticklebacks, but these animals can usually be excluded. More disconcerting are the swarms of plankton which at times pour into the filters with the raw water. At the Antwerp works no less than 10 tons of minute crustaceans, chiefly those allied to Daphnia (Fig. 83, *a*), were screened off in the course of a few weeks. Mr. Watts, President of the Association of Water Engineers, referred in 1899 to the overwhelming development of Cyclops (Fig. 83, *b*) in a service reservoir which he had constructed.

Efficiency of Filtration in Relation to Character of the Sand.—othing has been done to prove that the actual shape of the rticles of sand has much to do with the efficiency of the filter. is desirable that the material should be of fairly uniform ade, so as to equalize the resistance and keep the flow uniform roughout the bed. Dr. Frankland instances the Königs-rg filters, which worked indifferently in 1892, and there the id was of very unequal grade. This may not have been the ef cause of the defects, but Director Pennink and others lay ess on uniformity of grade. There is an inclination to our sharp, angular sand, crushed quartz, etc., but, as the ticles soon take on a gelatinous covering, there cannot be ch importance in mere shape. It is, however, true that nded particles present a smaller surface than an equal ght of angular sand of like grade, and a certain disadvantage y lie in the fact. Such benefit as may attach to an enlarge-nt of the surface would not be apparent until the slimy ering had been formed. Sands containing chalk increase hardness of the water for a time, while those rich in oxide ron aid oxidation, probably by contributing a modicum on to the gelatinous coat.

he readiness with which the gelatinous coat forms depends n the quality of the raw water. Waters that are naturally ure, from lowland streams, from the surface of cultivated s, shallow wells, and such sources, bring along with them proper materials for coating the sand. Water from deep ngs and wells does not easily supply these materials. In the more contaminated the raw water is, the better is it ted to develop in the filter-bed the slimy viscous tissue h will surely accomplish its purification.

nd which is obtained from natural deposits consists largely rticles of quartz, an insoluble substance which does not to weathering, and is regarded as one of the final residues e disintegration of rocks by the forces of Nature. There nfinite varieties of sand as judged by size and shape e particles, by the colour and transparency of the s, by the percentage of foreign matters, as earthy tes, chalk, iron oxide, etc. In selecting a sand for a bed, the chief points which claim the attention of the eer are—(1) the size of the particles, (2) the uniformity ade.

Effective Size of the Grains.—Since the experiments made at Lawrence in 1892, it has been usual to give a definition of the *effective size* of the granules of a sample. In river sand, for example, the diameters of the particles may range from $\frac{1}{500}$ to $\frac{1}{5}$ inch or more. The effective size is defined as the size of a particle such that 10 per cent. of the sample by weight consists of smaller and 90 per cent. of larger particles. The effective size at the Metropolitan Waterworks is $\frac{1}{70}$ inch ; at Berlin, Hamburg, and Altona, it is slightly less ; at Antwerp, $\frac{1}{84}$ inch ; and so on. Mr. Baldwin-Wiseman has analyzed sands from many filter-beds, using for this purpose a set of thirteen sieves with 6, 10, 20, etc., up to 200, meshes per linear inch. He thus obtains a number of fractions of different grades, and arrives at the size of an "ideal" granule representing the dimensions of the grains in each of these portions. Further, the size of an ideal granule indicating the average of the whole is easily calculated. This method of analysis affords a very complete account of the constitution of a sand-bed, and it has been applied by Mr. Baldwin-Wiseman in many interesting investigations (Proc. Inst. of Civil Eng., 1910).

Relation of Effective Size to Rate of Filtration.—In the course of the Lawrence experiments, it was shown that the rate of discharge through a sand-bed was intimately related to the effective size of the granules. When the head of water was $\frac{1}{100}$ of the thickness of the sand, the water percolated through a freshly cleaned bed three times more quickly when the effective size was $\frac{1}{70}$ inch than with an effective size of $\frac{1}{125}$ inch.

The frictional resistance of sand to the passage of water has its origin to a large extent in the adhesive force of the surface of the granules, and the larger this surface, the greater is the retardation. A close approximation to the total area of the surfaces of the sand-grains per cubic foot is obtained by fractioning the sand, and reckoning from the various grades. We may in calculating look upon the granules as spheres or cubes, and thus deduce the number of grains in a unit volume and the total surface of all the granules. For example, the openings of a sieve with 100 meshes per inch would be $\frac{1}{160}$ inch across, allowing for the thickness of the wire. Many millions of grains just capable of passing such a sieve would go to make

up a cubic foot, and the total surface of all would be, roughly speaking, 5,000 square feet. This is nearly ten times the total surface of a cubic foot of grains $\frac{1}{25}$ inch in diameter. In the case of dune sand from Haarlem, the total surface per cubic foot, reckoning all grades present, was on trial found to be 3,600 square feet. A sample of filtering sand used in Scotland gave less than one-half of that amount. Fine sands, such as those used at Amsterdam and other places in Holland, are most suitable for treating waters that have either been pre-filtered or are naturally free from turbidity.

Various attempts have been made to deduce a formula which would express the rate of discharge from a filter-bed of known composition. It is clear that the amount of water which filters in a given time is proportional to the head of water directly, and inversely to the thickness of the sand. Thus, any formula proposed will necessarily contain as a factor

$$\frac{\text{Head of water}}{\text{Thickness of sand-bed.}}$$

This is usually written $\frac{h}{l}$.

The Lawrence formula multiplies this fraction by the square of the effective size (d), so that the essential part of the formula is $d^2\frac{h}{l}$. A correction must be applied for change of temperature, as warm water, having less viscosity, percolates more quickly than cold.*

Area of the Surface of the Sand, and Thickness of the Water-Film.—Instead of drawing the effective size into our calculation, we may consider the total area of the surfaces of the sand-particles per cubic foot, and the thickness of the film of water adherent to this when the sand is thoroughly moistened. The amount of water which a cubic foot of sand will retain in virtue of its "porosity" is found by weighing the sand when wetted and when dry, and the thickness of the adherent film is then calculated. Mr. Baldwin-Wiseman has examined a large number of samples of sand of various grades with respect to

* The Lawrence formula is $V = cd^2\frac{h}{l}\left(\frac{t^\circ \text{ Fah.} + 10^\circ}{60}\right)$, where c is a multiplier which is approximately equal to 850 (with + or − variation of 150 according to circumstances) when the sand is new, and ranges from 500 to 700 in the case of sand that has been used for several years.

the water retained, and he has found that the thickness of the water-film increases rapidly up to a certain point as the size of the granules is augmented. Sands of grades ranging from $\frac{1}{25}$ to $\frac{1}{100}$ inch have nearly equal porosities; they all retain 55 to 60 per cent. of their own volume of water. But the total surface of the granules in the finer grades is very much greater than in the coarser, so that the same volume of water approximately is spread over surfaces of very different extent. In fact, the adherent film is $\frac{1}{500}$ inch thick when the grains have a diameter of $\frac{1}{75}$ inch, and five times that amount with granules of $\frac{1}{25}$ inch. In making this computation, the assumption is made that all the retained water is distributed as a film of uniform thickness. This may not be strictly true, for with coarser grades the porosity is not so great, and the film appears to become thinner again. It must not be overlooked that in the finer grades of sand there is ample play of capillary attraction and for the viscosity of the water, so that all the interstices are filled up, and much more water may be retained than would suffice to provide a coating for the granules.

Relation of the Thickness of the Film to Speed of Percolation.—Putting aside considerations based on capillary action, and reckoning the whole of the retained water as distributed in a film, Mr. Baldwin-Wiseman shows that the rate of discharge from a filter varies directly as the thickness of the film. He has deduced a formula somewhat similar to the Lawrence result, in which the factor d^2 is replaced by an expression which takes account of the percentage porosity, the thickness of the film, and the area of the surface of the grains of sand. As might be expected, the rate of percolation is inversely proportional to the area of the granules. That is to say, the greater the total area of the surfaces of the grains of sand per unit volume, the more slowly does water filter through.

Uniformity of Grade.—It has been pointed out by many authorities, and in particular by Director J. M. Pennink of Amsterdam, that the frictional resistances throughout the filter-bed should be as uniform as possible. This condition is most easily obtained with a sand of even grade.

There are several methods of estimating the degree of uniformity in the size of the sand-grains. One that naturally suggests itself is to take account of the weights of the fractions

into which the filtering material may be divided by a series of sieves. A sample of excellent sand analyzed by the authors was so uniform in grade that three-quarters of the whole weight passed through the fourth to the seventh sieves of a set of twelve. The range of grade for the largest portion of the sand lay between $\frac{1}{40}$ inch and $\frac{1}{100}$ inch in diameter. Dune sand is notably fine and uniform in grade. River sands usually vary considerably, and, as it is hardly supposable that a uniform mixture of the various sizes of grains is to be found all over the filter-bed, there are necessarily variations in the frictional resistances at various places.

Coefficient of Uniformity.—Allen Hazen defines a *coefficient of uniformity* which has been adopted in America. This may be expressed by the value of the following fraction :

$$\frac{\text{Diameter of the grain such that 60\% of the sample is finer than itself.}}{\text{Diameter of the grain such that 10\% of the sample is finer than itself.}}$$

For instance, in the case of a sample of high-class sand tested, 60 per cent. by weight was finer than $\frac{1}{50}$ inch, and 10 per cent. was finer than $\frac{1}{100}$ inch. The quotient of these two fractions $(\frac{1}{50} \div \frac{1}{100})$ is 2, and this is the required coefficient. In another case, a river sand which had been screened to $\frac{1}{8}$ inch and under proved to have 60 per cent. of the granules finer than $\frac{1}{32}$ inch, and 10 per cent. finer than $\frac{1}{80}$ inch. The coefficient was higher in this case, namely, 2·5, indicating that the sand was more divided up into different sizes.

Best Grade of Sand.—Attempts have been made to settle the optimum grade of sand for filtering purposes, but this point cannot be decided without taking account of the quality of the water to be treated. The experiments at Lawrence, and the working of the filters at Amsterdam, Paris, etc., show that the best bacteriological work is done by sand of fine grade. A layer of fresh sand 5 feet thick, and composed of grains from $\frac{1}{150}$ to $\frac{1}{200}$ inch in diameter, is nearly as effective a safeguard against bacteria as a Berkefeld kieselguhr candle. But the frictional resistance is great. With an effective head of 1 foot a clean bed of this grade would hardly pass 1,000,000 gallons per acre per day. With the formation of a film on the surface the output would soon be reduced, so that economical working would be out of the question. In short, the grade of sand

must bear a relation to the turbidity of the water, and if the first filtration is insufficient bacteriologically, it is better to repeat the process with finer grades.

For general purposes Hazen suggests an effective size of about $\frac{1}{120}$ inch, and this should not be too fine for waters that have been cleared by sedimentation or prefiltration. It is presumed that the sand has been screened to exclude all coarse particles by separation through a sieve with six or eight meshes to the inch. It is to be noted that the effective size tends to rise after the filter has been in use, as the finer particles are carried away in the process of washing.

Depth of the Sand-Bed.—The depth of the sand-bed has important bearings on the efficiency of its operation. A minimum of 1 foot is prescribed by the authorities at many places, but it is certain that the most reliable working is obtained with beds two or three times as thick. With a thin layer of sand too great a responsibility is thrown upon the filtering skin, and the purifying agencies of the sand itself are not fully taken advantage of. Besides, if the film is damaged at any part, the frictional resistance of a shallow bed is small, and much water of inferior quality escapes. A head of 1 foot may drive water through a filmed bed at 4 inches per hour, but if the film breaks, and only 1 foot of sand of effective size ($\frac{1}{80}$ inch) lies underneath, the water will race through at many times that speed, sweeping with it numbers of bacteria adhering to the sand. Herein lies one of the main risks of sand-filtration under a pressure of water. It would be prudent to bear in mind the importance of keeping as low as possible the ratio $\frac{h}{l}$. It would be wise to have it stipulated that $\frac{h}{l}$ should not exceed unity; that is to say, the limit of head for a bed 2 feet thick should not go beyond 2 feet.

CHAPTER VI

THE MANAGEMENT OF SAND-FILTERS

Regulators.

is unnecessary in these days to enlarge upon the desirability avoiding sudden alterations of pressure on the surface of a ·er. The consequence of such is to endanger the continuity the filtering skin, and to encourage irregularity of flow in ə lower strata, whereby germs are detached from the granules d swept into the filtrate. To illustrate the evils of quick əssure change in the case of mechanical filters, the case may mentioned of a town at which a filter of this kind was erposed upon the main, the treated water passing directly distribution. It was noticed that a rupture of the film was ;urring every now and then, and inquiry showed that there s a hydraulic lift in the town, and that the breakage of the n was coincident with the use of this lift. The addition a service reservoir was here an obvious necessity. It is ıerally recognized that proper adjustment of head cannot arrived at unless the effluent be controlled by a regulator, l discharged into a basin which is to feed the mains.

[t is clear that the thickening of the filtering skin and the posit of sediment thereon will demand an increase of head to ıintain uniformity of percolation. There are two ways of sing the pressure on the filtering-bed, and in both cases tomatic regulation is practicable—as it is, indeed, most to be sired. The first method of increasing head is to augment the pth of the crude water overlying the sand, while keeping the ·el of the water at the outflow constant. In Britain this :angement is the usual one, but on the Continent it is ɔre usual to find that the depth of the water over the sand-ds is maintained unvaried. In this case change of head is

effected by raising or lowering the water-level in the outflow chamber.

At less modern installations, where the regulation is by hand, it is quite usual to see a combination of both methods. The inflow of water to the filters being steady, the depth gradually increases as the resistance below develops in strength. At the same time the telescopic tube at the outflow is brought into use to further augment the head.

The point to be kept in view in this matter is that the same quantity of water should pass through the bed in the same time. Hence the rate of discharge should be invariable once the filter has matured.

Siphon Regulator.—One device which will secure a uniform flow is based upon the principle of the siphon. The rate of discharge from a siphon is dependent on the bore of the tube, and on the difference between the water-levels at the inlet and the outlet. Thus, with any given size of tube, the maintenance of a fixed difference of level between inflow and discharge secures a constant output. How this is adapted to an automatic regulator will be understood from the diagram of the Didelon Patent Regulator (Fig. 16).

The siphon is supported by the framework M, which rides on the float F, and the whole is steadied and partly counterbalanced by the weight and cord on the pulley D. One leg of the siphon dips into a chamber to the left, which receives filtered water through the valve A; the other ends in a basin, G, which acts as a water-seal. As the float ascends, it tends to close this valve, while a movement in the opposite direction opens it.

To make the discharge of the siphon variable at will, it can be raised or lowered by turning the hand-wheel E, which moves the screw V. In the figure the difference of level between the water surfaces in contact with the right and left arms of the siphon is denoted by h. Raising the siphon diminishes h, and so lessens the outflow. Lowering it has the contrary effect. By a preliminary trial one can set the apparatus to discharge the required number of gallons per minute. Owing to the motion of the float, which conforms to that of the water-level in the valve chamber, the rate of discharge fixed upon cannot vary. To the frame M is attached a scale, and to the spindle

V a pointer, which enables the speed of filtration to be read off at a glance. It will be noticed that the water-seal G has a guide-roller, R, and a counterpoise. The water-seal prevents the access of air, and the counterpoise, together with that at C,

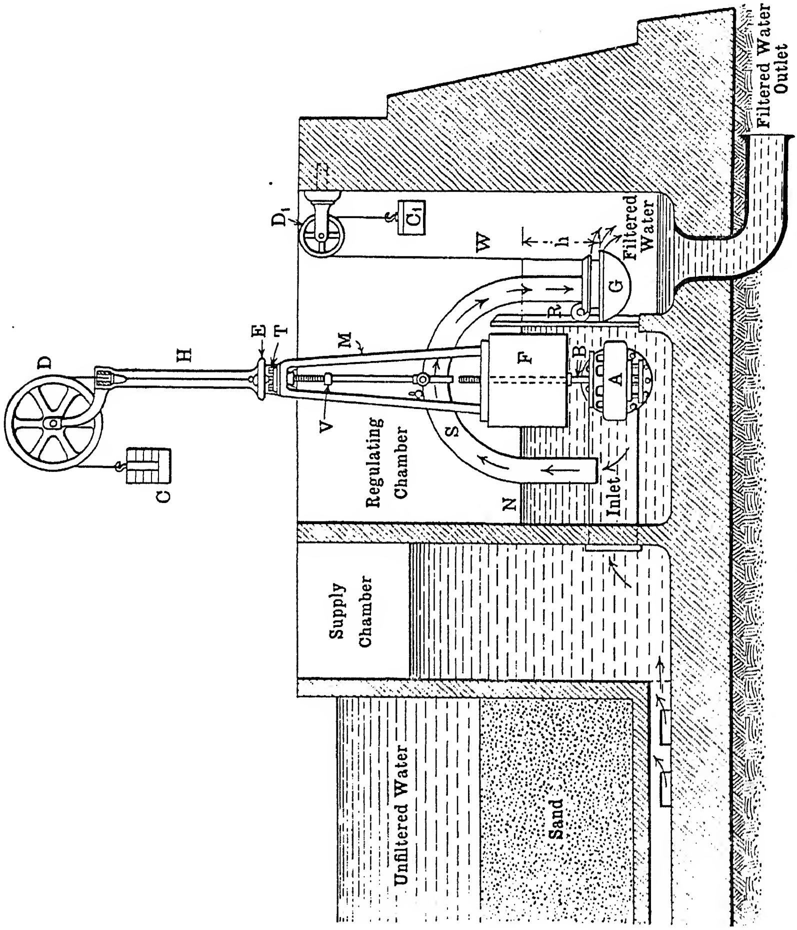


FIG. 16.—DIDELON AUTOMATIC REGULATOR.

A, valve; B, spindle; C C_1 weights; D D_1 pulleys; E, handwheel; F, float; G, water seal; H, frame; M, supports; N, water-level; R, roller-guide; S, siphon; T, screw to E.

carries so much of the weight of the structures connected with the float that the latter does not require to be large.

As the resistance of the filter-bed becomes greater and greater, the level of the water in the valve chamber sinks, and increases the head. To complete this automatic device a writing pointer carried by the weight C may be made to press

against a revolving drum, so that the variation of the head which yields the given output can be followed from day to day. Any rupture of the filtering skin would be immediately signalled by a rise of the float, and a corresponding dip in the line traced on the revolving drum.

The cost of the Didelon regulator as ordinarily supplied to large waterworks is about £80.

Telescope Regulator.—The simple telescope tube regulator is in frequent use in Britain and the Colonies, and in general the adjustment is made from day to day by hand. To find the number of gallons passing over the circumference of the tube, it is only necessary to know the depth of the outflow. A previous calculation shows what this ought to be in order that the rate of percolation through the sand-bed may be maintained at a standard value.

The depth of the telescope tube is varied by a screw which carries a horizontal pointer bearing on a vertical scale. The latter should not be nearer to the edge of the tube than 2 or 3 feet, because the water surface dips towards the mouth of the tube. When once it has been determined how far the tube should be depressed below the surface of the water in the reception chamber, the pointer may be adjusted at the required distance above it. The tube is then lowered from time to time so as to keep the end of the pointer at the level of the water. Or, alternately, the tube may carry the scale while the pointer has an auxiliary spindle.

A device by which the telescope tube can be made to operate automatically is supplied by Messrs. Glenfield and Kennedy, Ltd., Kilmarnock (Fig. 17). The tube is supported upon a counterpoised float, and is so affixed to a vertical spindle that the depth of its edge below the surface is exactly the number of inches that will give the output desired. As with the Didelon regulator, variations in the level of the water do not affect the rate of discharge. The cost of this apparatus is moderate, and it has been introduced at many stations, as Bolton, Portsmouth, etc.

Professor Burton's Automatic Regulator.—Other forms of regulators depend in principle on the flow of water over weirs or sluices adjusted to certain depths, or on the size of an orifice that may be enlarged or diminished by the movement of a ball

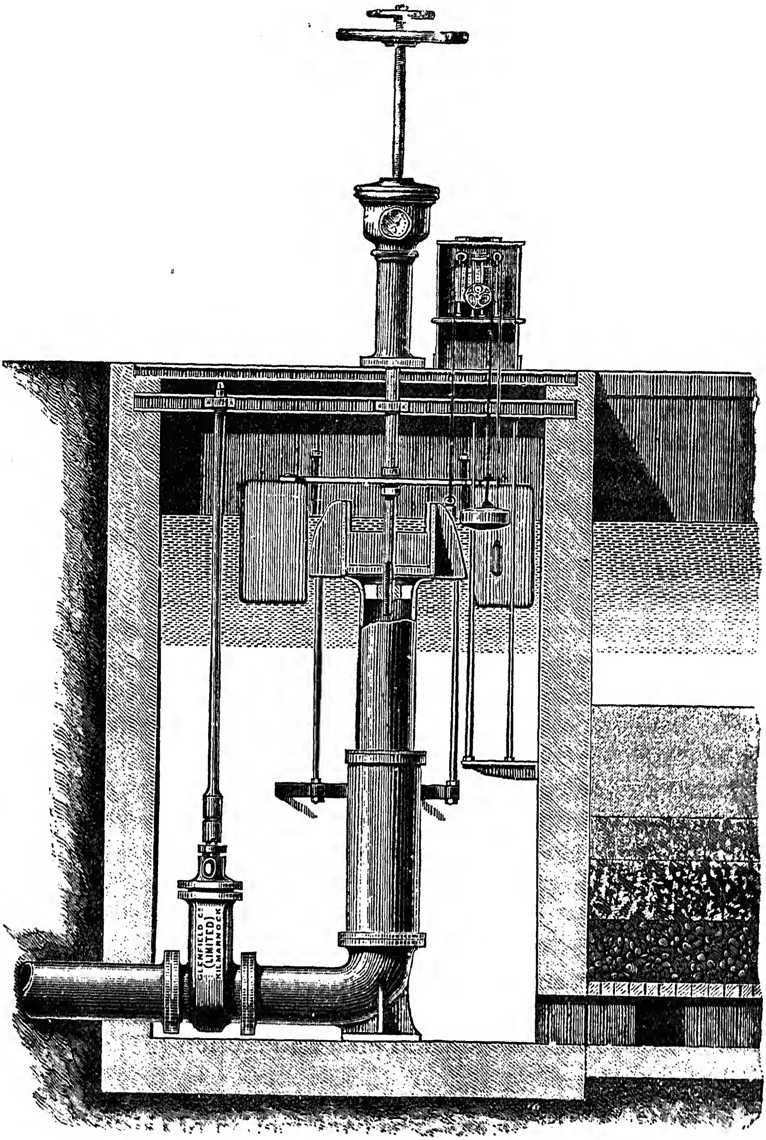


FIG. 17.—GLENFIELD AND KENNEDY'S TELESCOPE REGULATOR.

float. There is also the well-known regulator first installed at the Tokio Waterworks by Professor Burton, in which the flow of water through a balanced valve situated directly in face of a constriction in the conduit effects its own regulation automatically. The working of this regulator will be made plain by the accompanying figure, which is taken from the diagram in Burton's "Water-Supply of Towns," by permission of the publishers.* The constriction is at M, and the throttling of the tube at this point offers resistance to the current, so that a difference of pressure is set up between the water within and without the valve casing. The valve is seen at P, R, and on the spindle is fitted the piston T. The greater the obstruction produced by the constriction, the more will be the back-thrust upon the lower surface of the piston T, which experiences the pressure ruling within the valve casing. The upper side of the piston is under the pressure of the water outside the case, with which it is in free communication (Fig. 18A). The increase of internal pressure serves to raise the piston and valve P, R, and so to contract the orifice. When this happens, the difference of pressure is reduced, and a position of equilibrium is attained. The outflow through the constriction sets up just so much back-thrust as is sufficient to maintain the piston and valve in position.

Neither the valve nor the piston requires to work tightly, and as constructed the valve is a sensitive one, which quickly adjusts itself to cope with any variations of the current which enters at N, and establishes a permanent regularity of flow.

When there is not sufficient pressure in the inflow pipe to operate the valve, it is an indication that the filters are so far clogged that they cannot deliver enough current to fill the constriction, and that they require cleansing. When this condition has been arrived at, the valve suddenly drops down on the metal casing. The connections of three filters to the clear water basin are shown in plan and section (Figs. 18B and 18C).

The Weston Controller.—The construction of this apparatus will be understood from the accompanying diagram (Fig. 19). The outlet is an annular opening between the disc and the

* Burton's "Water-Supply of Towns," Messrs. Crosby, Lockwood and Son.

circumference of the discharge-pipe. A spindle passes through the disc, and is connected above to a float, and the interval

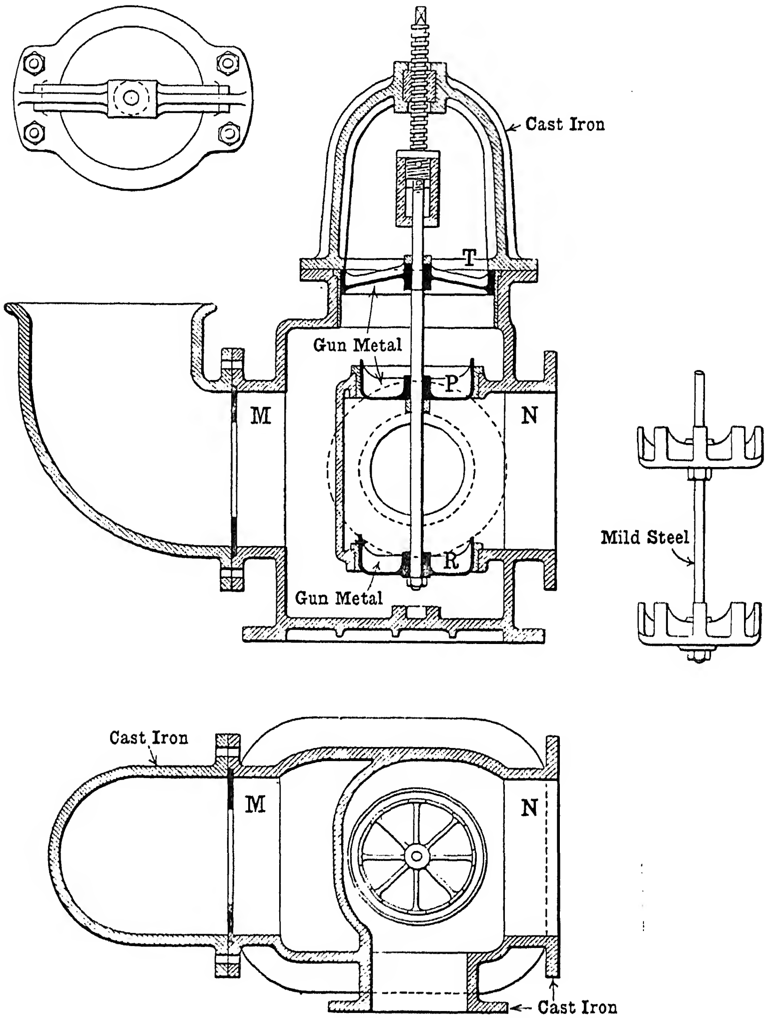
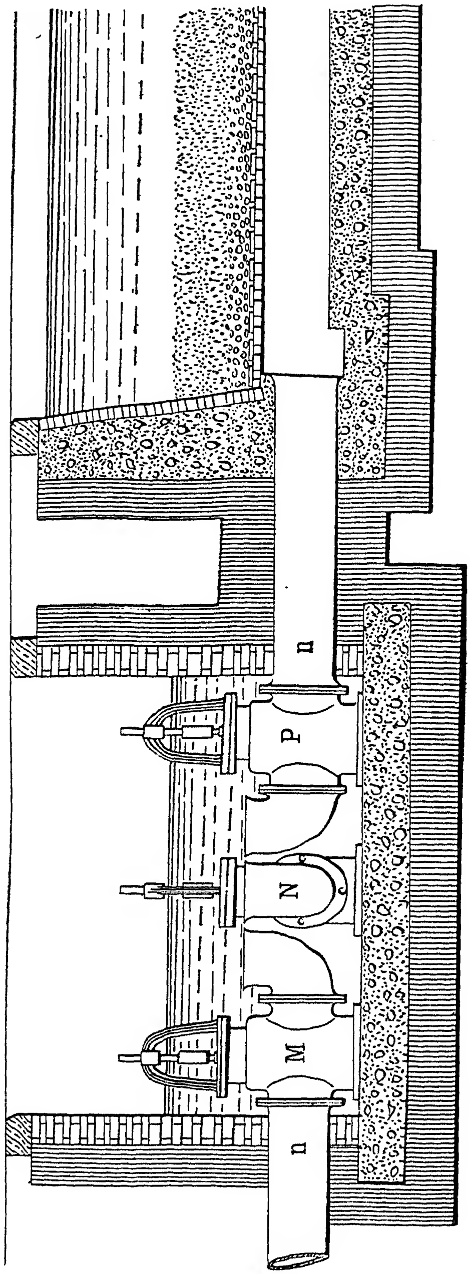


FIG. 18A.—BURTON'S AUTOMATIC REGULATOR.
(By permission of Messrs. Crosby, Lockwood and Son.)

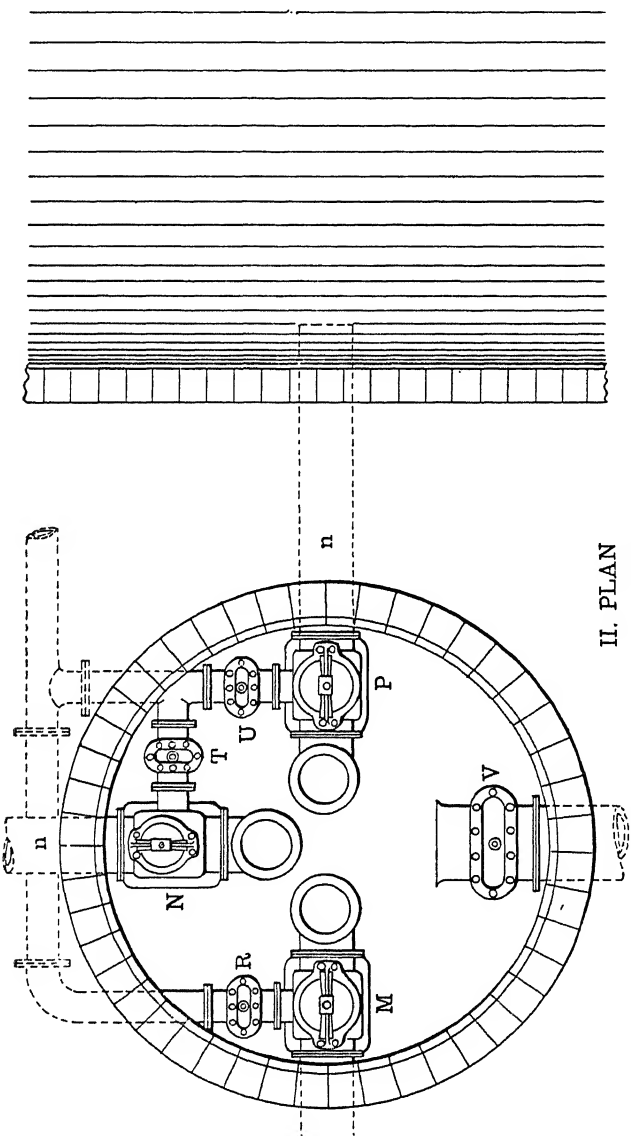
between disc and float can be adjusted. On the distance between these will depend the "head" which propels the water through the annular orifice.



I. SECTION

FIG. 18B.—BURTON'S AUTOMATIC REGULATOR.

(By permission of Messrs. Crosby, Lockwood and Son.)



II. PLAN

FIG. 18C.—BURTON'S AUTOMATIC REGULATOR.

(By permission of Messrs. Crosby, Lockwood and Son.)

From the float two valve rods descend, and engage with levers operating the inlet valves. Raising the float tends to shut down these butterfly valves, and lowering it has the opposite effect. The controller is therefore self-regulating.

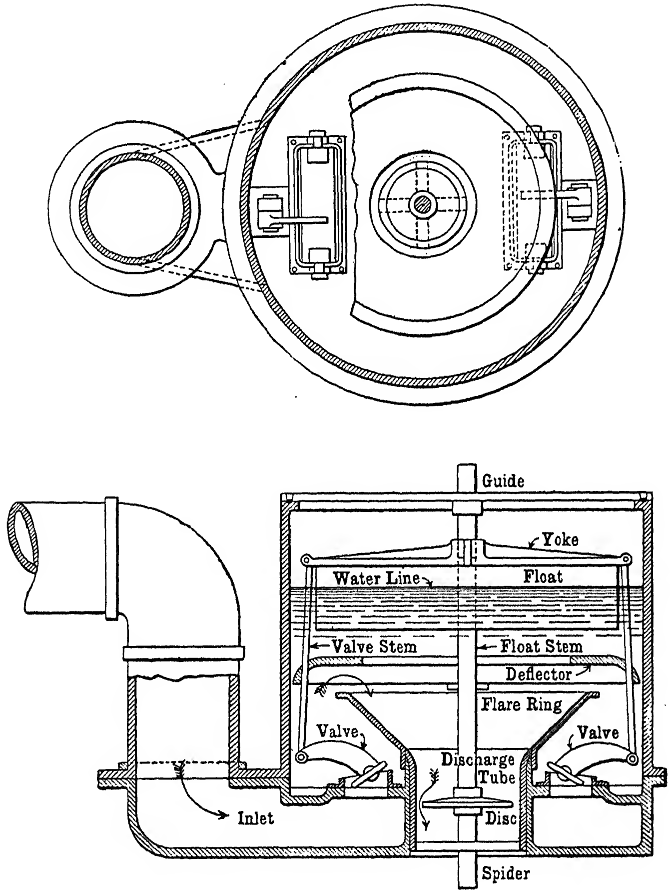


FIG. 19.—WESTON'S AUTOMATIC CONTROLLER.

In setting the apparatus to work, one first determines the number of gallons which it is desirable to withdraw from the filters per minute. The height of the float over the disc is then set on the spindle according to the instructions supplied with the apparatus. The spindle is next placed in position in the guides, and the inlet opened. Tests made with very different

pressures applied in succession to the surface of the filter show that the controller gives a steady output.

The range of the Weston controller as regards output may be greatly enlarged by varying the size of the disc, and thus employing a larger or smaller orifice as the circumstances demand.

As the filter becomes clogged, the butterfly valves will be more and more fully opened; and when the throttling of the inlet is quite removed owing to the descent of the float, it is inferred that the time for cleansing the filter is near. Further thickening of the filtering skin causes the level of the water in the controller to sink below the float. Thus, neither the management nor the setting of the regulator should cause any difficulty to an attendant.

THE MANAGEMENT OF SAND-FILTERS IN BRITAIN.

The efficiency and reliability of a sand-filter are intimately related to the method in which it is handled. The construction of the plant and the arrangement of the various units should be such as to facilitate good methods of working. Sand-filtration is the means used to purify the supplies of many of the largest towns in Britain, and therefore it will be of interest to compare the modes of procedure at a number (fifteen) of the most important centres.

1. If it be asked how many filter-beds are usually provided for each million of gallons filtered per day, the answer is that the numbers vary from one to six. Out of ten important installations, two use but one filter per 1,000,000 gallons, three have three filters, four have four, and one has six.

2. The speed of filtration ranges from 1,000,000 to 4,000,000 gallons per acre per day. The greater number, however, approach to 2,000,000 or 3,000,000 gallons per acre per day, and this may well be regarded as the average speed. If the water percolates at the rate of 1 inch per hour, the output per acre is about 540,000 gallons, so that 2,500,000 gallons per acre per day would indicate a rate of downward travel equal to 4·6 inches per hour.

3. With regard to regulation of the output and "head," this is attended to in most cases by hand, but at two of the most populous centres there are automatic contrivances.

4. The construction of the filters offers many points of comparison. At some stations the depth of the filtering materials is only 3½ to 4 feet, while at others it extends to nearly 6 feet. The average depth may be taken at 5 feet, and of that measure 2 to 2½ feet will represent the upper layer of fine sand. The lower strata consist of gravels, broken stones, and perforated bricks, their combined thickness being about 2½ feet.

5. The water stands above the sand-bed to a depth of 18 inches on an average, but there are wide differences in this respect. In some cases the depth is only 9 inches, while in others it is as much as 3 feet.

6. At all the places to which the foregoing particulars refer there is storage, and the volume impounded is sufficient to maintain the service for 130 days, taking the general average.

In some instances there is enough water stored to meet all demands for eight or nine months, but elsewhere one month's supply only is held in reserve.

The clear-water reservoirs are covered in the majority of cases. These reservoirs are intended to hold, on the average, about twenty hours' supply, if we leave out of count two stations where the service reservoirs would seem to act as an important supplement to the raw-water storage.

7. Periodical examination of the effluent is an important matter, but at half a dozen very large waterworks no examination whatever is made. The water had been pronounced satisfactory at first, and this has been looked upon as an adequate safeguard. At one or two of these places the manager professes to be able to judge the efficiency of the filters by observing the transparency of the filtrate. In other cases tests are made monthly, and sometimes, though this is rare, weekly, and at the largest undertaking in Britain thousands of samples from various filters are searched bacteriologically and chemically every year by highly trained operators.

8. Passing now to the time allowed for filming, it may be said at once that the practices at various stations show marked divergencies. However, in 60 per cent. of the installations the water first run after paring the sand-bed is turned directly into the clear-water tanks. The reservation is made in a few cases that the filter is only allowed to work very slowly for a time, but no water is run to waste.

In other cases, notably at one of the principal works in the

Midlands of England, each filter after paring is set to work at a low speed, but the filtrate is allowed to go to waste until the purity of the water is declared to be sufficiently high to permit of it being allowed into the supply. This is usually after twenty-four hours. At one important station in Lancashire filtered water is run into the cleaned bed from below to the level of the sand, and raw water is then admitted above. It is then allowed to stand for twenty-four hours. The filter is set to work very slowly. Obviously, it is not expected that a film would form in a day's time, the sediment closing the pores only in part. At the Egham Waterworks the newly cleansed beds are treated with a coagulant (see p. 144), so as to save time in making the filter ready to do its work with efficiency.

9. Periodically the sand-filter becomes overcharged with algoid growths and sediment, and paring has to be resorted to. In a certain number of cases the sand pared off is laid aside, and the thickness of the bed is in this way gradually reduced. The original thickness of the top layer of fine sand being about 2½ feet, a succession of thirty cleanings would reduce the depth of this layer to somewhere near 12 inches. The paring is not further proceeded with, as it is not considered wise to diminish the thickness of the bed beyond this point. What happens now is that the remaining foot of fine sand is trenched up, and washed sand is put under and next to the gravels. This can readily be managed by running a trench along one side, filling in the clean sand to a depth of 18 inches, and then throwing back the material shovelled up. The operation is repeated until the whole bed has been gone over. With this mode of operating the filter may require about six or eight parings per annum, and a trenching over once in three or four years.

At Birmingham (see Proc. Inst. Mech. Eng., Dec., 1909) the resanded filter is allowed time to mature, and it is found that in general *two* weeks must elapse before the bacteriological results are perfectly satisfactory.

In other cases the procedure is varied as follows: The 12 to 15 inches of sand left after repeated parings is wholly removed, and clean sand to the required depth is put in position.

The practice described above is one which maintains the uniformity of the depth of sand, but the top layer becomes thinner by degrees. A procedure followed at other waterworks preserves the sand-bed at approximately the same

thickness from year to year, but it entails a difference of thickness at the two sides of the sand-bed. The sand pared off at the first cleaning is washed, and deposited along one side in a strip which is, say, 6 feet wide. At the next cleaning the operation is repeated, only that the washed sand is placed in a strip contiguous to the last one. In this way the whole width of the filter is dealt with in time. Towards the end of a cycle of replacements it is clear that the sand adjacent to the side opposite to that at which the replacements began will be considerably thinner than the rest. Under the circumstances now detailed, it is evident that the resistance to the percolation of the water differs in different parts of the filter. It will be least at that side which is the last to receive a fresh layer of sand. It will be nearly uniform over the section which has already been recovered, and, again, it will be uniform over the area yet to be treated with fresh sand. But the resistance in the latter case will be less than in the former, and it will be increasingly less as the cycle of cleaning approaches completion. Efficiency, therefore, cannot be quite uniform over the filter.

10. Sand-washing is as a rule carried out in the stereotyped form of tank supplied by Messrs. Glenfield and Kennedy, Ltd., and other makers. At half the number of installations referred to above, the sand-washer is placed at the middle of the filter-bed, and the necessary connections are made for admitting wash-water, and withdrawing the overflow. The latter is generally led to a sump in which the greater part of the coarser particles in suspension are parted with. The disposal of the wash-water is occasionally a matter of concern to the water undertaker, and each locality has its own particular problem to solve in connection with this business.

When the sand-washers are not set in the middle of the filter-beds, they are located as conveniently as possible to facilitate the transport of sand. Thus, they are laid down between pairs of beds, or at a point adjoining the corners of three or four beds. Mechanical sand-washers do not appear to have found much favour as yet among the larger companies, for only at one or two stations are they in use. At Leeds, Leabridge, Birmingham, etc., a central washer on rails, designed by Mr. Greenway (James Gibb and Co., London), is found to serve its purpose well, and at Liverpool there is a portable sand-washer designed and made at the waterworks.

At Birmingham the washing stages are situated at the end of the series of thirty beds. Sand is transported to and from the stages by means of a light railway. Any sand which is not immediately required is stored in two empty filter-beds adjacent to the terminus of the railway. Here also Greenaway's patent washers are in use, driven by water-motors, and they can put through 8 or 9 cubic yards per hour.

Removal and subsequent replacement of sand is usually carried out by the labourers, who convey the parings to the sand-washers in barrows wheeled over planks, and distribute the washed material in the same fashion. The workmen who tread on the sand-bed are in general provided with overall boots, and care is taken that there shall be no contact with anything that would cause contamination. Smoking is forbidden as a rule.

Before paring, the water in the filter-bed is allowed to sink down a few inches below the surface, and before restarting filtered water is introduced from below till the level is raised above the sand. Raw water is then allowed to enter by the usual channel. Such is the method of operation in vogue at a number of waterworks.

11. The intervals between successive parings vary with the season, also with the nature of the crude water and with the length of time during which it has undergone sedimentation in the storage reservoirs. In fact, the divergencies are so great at the stations now under review that no very useful purpose is served by striking an average.

It may, however, be noted that the minimum period reported is two days, that the next lowest is seven days, and that at five places the shortest interval is fourteen days. On the other hand, the maxima range from 18 to 250 days. The average length of a run at eight installations in Scotland, where the deviations from the average at the several places are not abnormal, is exactly twenty-eight days. The daily output at these eight places is 37,000,000 gallons, so that the results deduced may be taken as fairly representative of the northern division of the kingdom.

The average period of twenty-eight days which applies to Scotland would represent very nearly the mean value for a number of waterworks in the North of England, but at most of the great English cities the local circumstances are unique, and often widely divergent from the others. Each supply, therefore, must be considered on its own merits.

12. The average annual cost of maintenance per 1,000,000 gallons filtered per diem is £137. This refers to a total of more than 300,000,000 gallons of daily output. If we exclude the Metropolitan supply, the average cost of treatment works out somewhat lower, and may be taken at £120. Corresponding to the latter figure, the cost of treating 1,000,000 gallons by sand-filtration is 6s. 6d. This does not include charges for depreciation, or for redemption of capital and yearly interest on the same.

13. Filters are occasionally protected from the effects of violent winds, which raise up waves and disturb the filtering skin.

General Regulations for the Construction and Management of Sand-Filters.—We may summarize in a concise form the principal considerations that deserve attention in the construction and management of sand-filters. It must be understood that there are likely to be special regulations in addition to these at each particular installation.

1. The filtering area should be of such dimensions that there is a sufficient reserve to insure the delivery of the necessary supply under all conditions of the raw water, and it should be divided into several beds, so that cleaning may be done without interrupting the work of purification.

2. Each filter-bed should be provided with a regulator, so that the velocity of the flow may be under control. Sudden fluctuations of the rate of percolation are to be avoided. The head of water should never be so great as to endanger the continuity of the viscous skin. Bacteriological investigation will indicate the limit of pressure that is to be considered safe.

3. The effluent should be readily available for sampling as soon as it leaves the filter.

4. Bacteriological analyses should be frequently made, more especially after cleaning, and after the filtered water has been allowed to pass into the service reservoirs or mains. Periodic examinations of the bacterial content should be recognized as a necessity when the filter is running normally, and special tests should be made when the conditions appear to be abnormal. The presence of *B. coli* in the effluent is very objectionable, and if it is detected in less than 40 cm^3. the efficiency of the filter must be regarded as doubtful.

5. There should be determined by experiment the time that

ought to elapse between the cleansing of a bed and the delivery of the effluent to the service reservoir. If the tests referred to in No. 4 above are regularly made, the average time that has to be allowed before the water attains the required degree of purity may be ascertained.

6. The thickness of the filtering layer should be sufficient for the local conditions, and never less than 15 inches.

7. The walls and floor of the filter must be water-tight. Under no conditions should unfiltered water be able to find its way to the effluent conduit.

8. There should be appliances for the proper washing of the sand, and, wherever practicable, the contact of the workmen with the material should be avoided.

9. Special regulations should be drawn up for the management of the filters in cold weather, more especially in times of frost. Algæ not being active in winter, the period between two cleanings will probably be greater, but the time needed to form a new skin will be longer.

FORM OF DAILY REPORT ON THE CONDITION OF THE SERVICE WATER.

The method of recording the daily observations made at a filtering-station exemplified below is similar to that in use at Antwerp. The entries refer to the filter-beds at a large installation in Scotland.

TABLE VIII.

Number of Filter.	Age of Filter (Days).	Head of Water (Inches).	Rate of Filtration (Inches per Hour).	Bacteria on Gelatine at 20° C. (per Cm^3.).	Of these the Number liquefying.	Colour of Water.	Remarks.
1	17	11	4	28	2	Clear	High wind, reservoir much disturbed.
2	25	13	4	25	1	Very clear	Filtering skin of No. 2 is disturbed in places owing to the ascent of the algæ.
3	4	3½	2½	34	0	Clear	—
4	8	5	3	51	1	Clear	Output per acre of sand per day, 1,800,000 gallons.

Admission of Water to Filter-Beds.—The entry of the crude water upon the filter-bed is very likely to disturb the sand around the point of inlet. The filtering skin forms slowly and imperfectly underneath the diverging currents, especially when the water stands only a few inches in depth. The fine silt which would seal the pores is carried outwards, and the algæ and other things that would seed the top layer are not allowed to settle.

It is usual to lay a small area around the inlet with flagstones or cement on a suitable understructure, so that the disturbance caused by the inflow may not be communicated to the sand directly. This arrangement is exemplified in Fig. 20. Here the inlet is seen to open at the level of the sand, but it is intended that, as the level of the water rises, the mouth of the inlet tube shall be brought up to the surface by inserting short lengths of conical pipe. The outlet from the filter-bed represented in Fig. 21 is of a design in common use.

At many waterworks there are inlet chambers with regulators, from which the current passes outward in a broad stream. The more the inflow is spread out, the less the velocity of the water. It may be distributed from end to end of one side of the filter-bed by means of inlets from a channel running parallel to that side. At most of the Puech-Chabal installations the water arriving at a filter-bed is made to cascade on a flight of low steps built along one side, both to perfect the aeration and to spread the flow. At the Antwerp works the water passes from the supply channel over a broad weir, and descends to the filter in a fan-shaped cascade, being caused to broaden out as it descends by means of short vertical baffles fixed on the steps. At other waterworks the depth of water overlying the sand is kept the same during a run, and the head is arranged for at the outlet. There is little risk of the filtering skin being disturbed in such cases, as it lies well below the surface.

Sand-Washers.—Mechanical sand-washers are in use at many installations, with the view of reducing working costs and economizing wash-water. A very satisfactory process is that of Hardy and Padmore's machine. The sand is first thrown upon a cylindrical screen, slightly inclined and kept in rotation. Jets of water spray the dirty sand and break it up. The loosened grains pass through the screen to a hopper, which

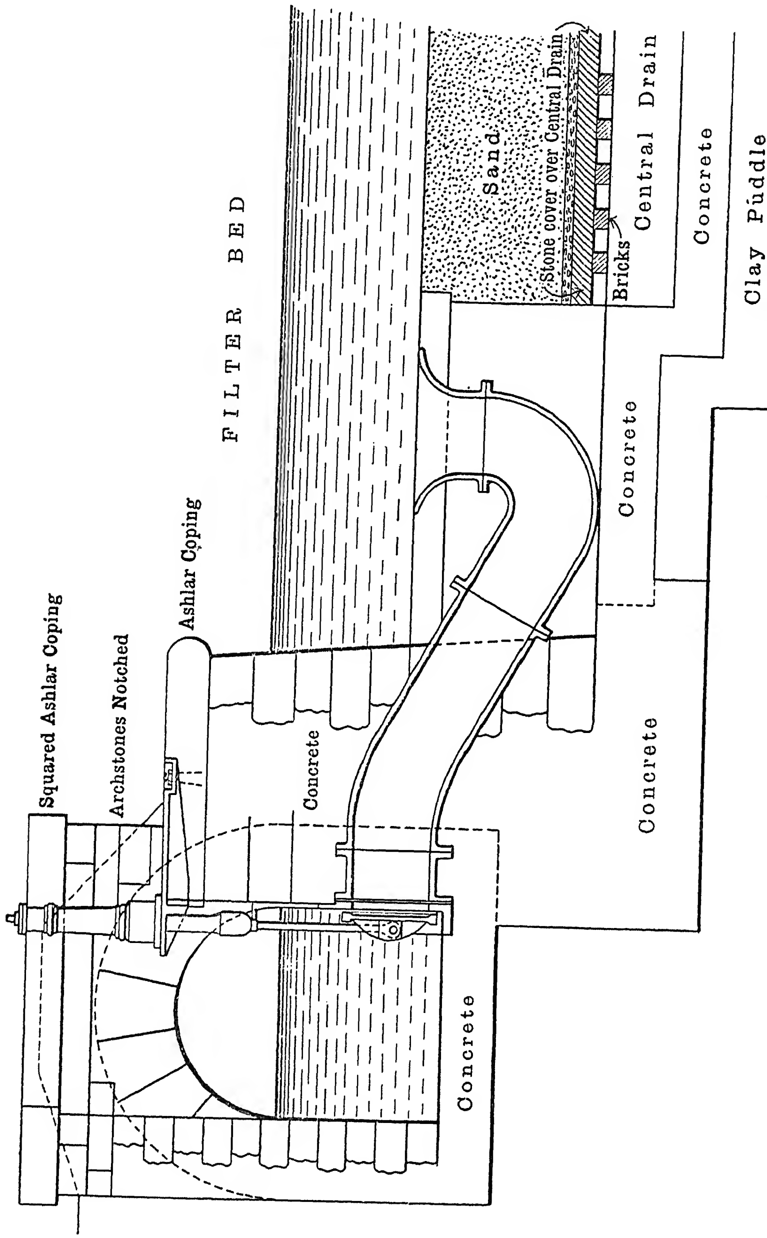


FIG. 20.—SECTION OF OUTLET FROM CANAL TO FILTERS.

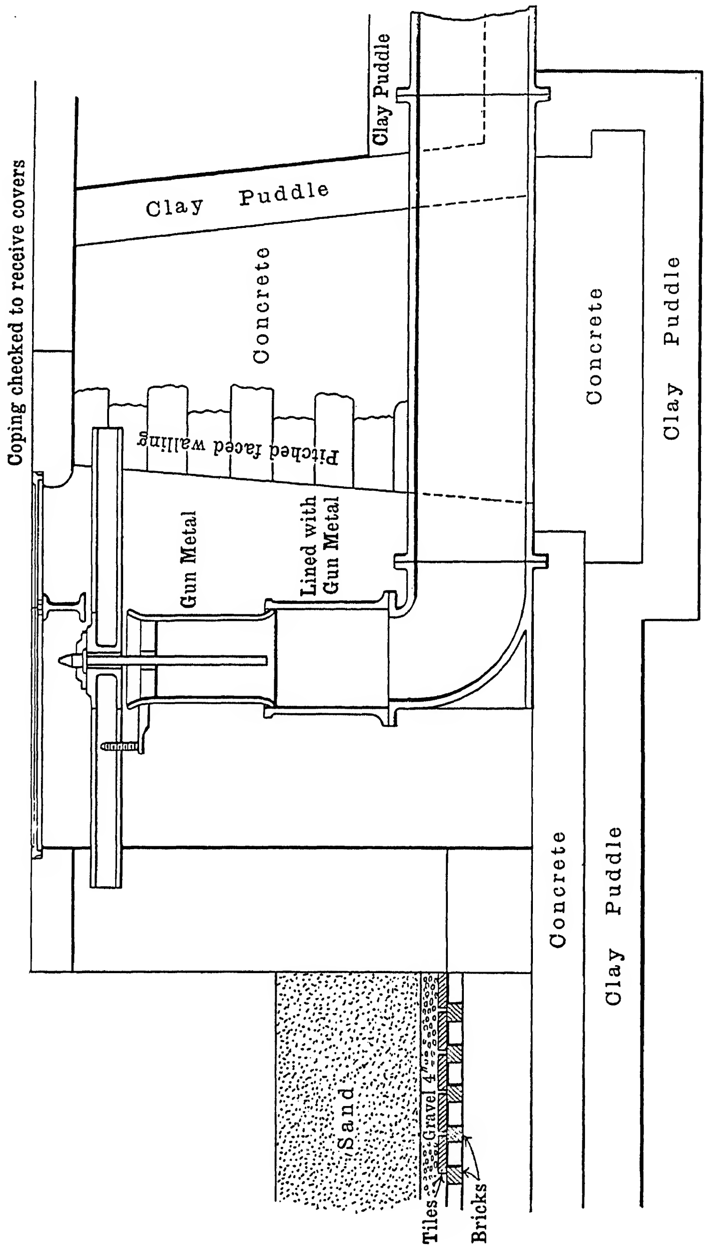


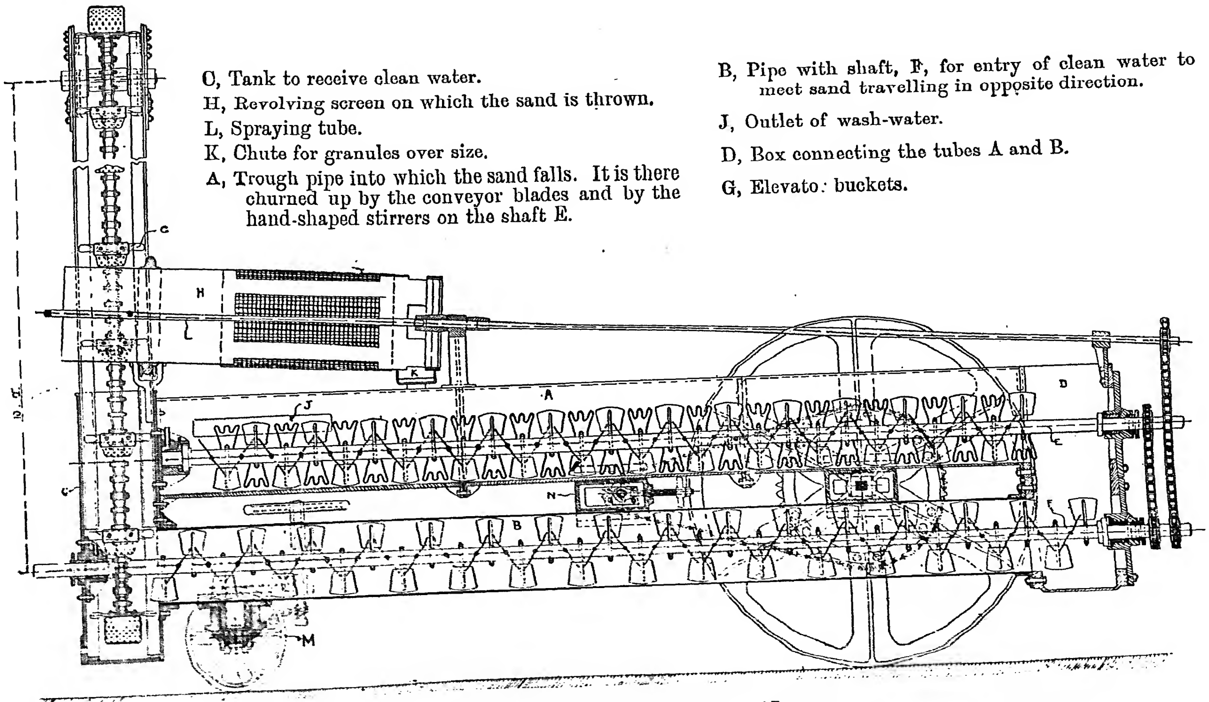
FIG. 21.—SECTION OF OUTLET FROM FILTERS TO RESERVOIR.

delivers its charge to a horizontal tube. Along this the sand is propelled by a series of paddle-blades arranged upon a central axis, and meets on its way an oppositely directed current of water. As it leaves the tube, the washed sand is caught by an elevator, and discharged at a convenient point. A recent improvement consists in the fixing of hand-shaped stirrers (Fig. 22).

The motive power required is small, and in general a water-motor is brought into service. In that case the exhaust water from the motor is employed to supply the washing tube. The machine is automatic, save that the sand must be filled in by hand. The economy in respect of manual labour is said to be about 75 per cent., and it is claimed that the sand is thoroughly and uniformly cleansed. The cost of a Sand-washing Machine to deal with 4 cubic yards per hour, inclusive of an oil motor and all gearing, does not exceed £230.

The conical sand-washer, in which the sand is cleansed by a jet of water under pressure playing from the apex of the cone, is a convenient and moderately priced apparatus when there are no special appliances for cleansing the sand. The wash-water overflows by a spout at one side, carrying the dirt with it. The washed sand is tipped into a barrow by turning the cone upon its trunnions. Everard's Patent Sand-washing Apparatus differs in principle from all the ordinary devices. It consists of a number of hoppers which communicate by inclined pipes. The foul sand is thrown into the first of the hoppers, and is impelled into the bell mouth of the communication pipe by a jet of water under pressure. It is thus driven over to the next hopper, where it is again thrust forward by a second jet, and so on, till it reaches the last of the set. It is there directed into barrows, or otherwise disposed of. Overflow pipes remove the wash-water to a settling chamber.

Specification and Estimates for Construction of English Sand Filter-Beds, etc., for a Supply of One Million Gallons of Water per Day, exclusive of Cost of Land.—Let it be assumed that water filtration works are to be constructed for a town of about 30,000 inhabitants, and that the town is requiring 1,000,000 gallons of water per day for all purposes, the method of filtration proposed being that of the ordinary open sand-beds constructed in a substantial manner of the best materials, and under efficient management and supervision. Sufficient



C, Tank to receive clean water.
H, Revolving screen on which the sand is thrown.
L, Spraying tube.
K, Chute for granules over size.
A, Trough pipe into which the sand falls. It is there churned up by the conveyor blades and by the hand-shaped stirrers on the shaft E.

B, Pipe with shaft, F, for entry of clean water to meet sand travelling in opposite direction.
J, Outlet of wash-water.
D, Box connecting the tubes A and B.
G, Elevato: buckets.

FIG. 22.—HARDY AND PADMORE'S PATENT SAND-WASHER. (JAMES GIBB AND CO., LONDON.)

land must be purchased to admit of extension as required, and in all the best filter works the beds are so arranged as to have one bed always out for cleansing and filming; thus it will be seen that three beds are required, *each of sufficient size and capacity to filter* 500,000 *gallons per day.* It is desirable that enough land for erecting two additional beds should at the outset be acquired, so that when necessary a sufficient area for extensions should be in the hands of the authority.

Provision should also be made for the construction of a pure-water reservoir, into which the filtered water may be conveyed from the filters before being turned into the town mains for distribution; this service reservoir should be of at the least sufficient capacity to contain a day's supply.

When such storage is provided, the filtration can be better controlled and kept regular, this being a most essential point in all well-managed works, insuring a better and constant effluent from the beds.

The general arrangement of such a sand-filter scheme is to be economically designed, so as to allow for extension and sufficient room for working to the best advantage. In the annexed estimate on p. 128 no provision or calculation has been made for the construction or for the cost of the pure-water reservoir, nor of the roads, approaches, or footpaths, round the filter-beds.

Filter-Beds.—The size and general design of the filter-beds themselves to be as follows: Each bed to be 200 feet by 75 feet by 7 feet 3 inches deep, and they are each calculated to filter 500,000 gallons of water per twenty-four hours, allowing 1·4* gallons per superficial foot of filtering area per hour, being at the rate of 300 gallons per square yard per twenty-four hours. The floors of the beds to be constructed of concrete in two layers, 8 inches and 4 inches thick respectively, the 8-inch layer of 5 to 1 concrete, and the 4-inch top layer of 4 to 1 concrete, the surface being rendered and trowel-smoothed. It is very essential that this finishing of the floor should be well carried out, plasterers being employed for the purpose.

The side, end, and division walls to be built of brickwork and masonry, with concrete backing and hearting, in a substantial

* Rate = 2·7 inches or 6·75 cm. per hour.

manner; the width of the division walls at the bottom is 5 feet 2 inches, and the top 3 feet 6 inches; the side and the end walls are 3 feet 4 inches at the bottom, and 2 feet 6 inches at the top. The portion below the sand-level to be built with the best bricks, backed with cement concrete 5 to 1; above the sand-level the walls to be composed of random-coursed masonry, with concrete backing as before. The coping on the whole of the walls to be of stone-dressed ashlar, drafted and chamfered, and set and jointed in cement mortar.

A main drain with semicircular invert to be constructed in the centre of each bed, lined with a single ring of radiated brick in cement coped with a course of Staffordshire blue brick, set in cement finished flush with the floor. The main drain to be covered with paving, which may be of reinforced concrete, tested to bear a weight of not less than 5 hundredweight to the superficial foot.

The whole of the floor in each filter to be covered with lateral drains of wire-cut red bricks, each brick made with two grooves on the underside, laid flat to form continuous channels, and close together. A longitudinal drain to be formed on each side of the filter, covered with tiles, and made to communicate with 4-inch stoneware ventilating pipes built in the walls of each bed.

The filtering medium to be composed as follows:

6 inches of broken stone or shingle, 2-inch to 1-inch gauge.
3 inches of gravel, $\frac{3}{4}$ inch to $\frac{3}{8}$ inch.
6 inches of gravel, $\frac{3}{8}$ inch to about $\frac{1}{8}$ inch.
30 inches of fine sand.

The filtering medium to be all of the best quality, and to be thoroughly washed in filtered water, screened, and sifted, to comply with the engineer's requirements.

The water to be taken into the filters from a C.I. main of sufficient size running alongside each bed to the inlet chambers, which are to be built at the end of each filter with brindle brick, faced inside with radiated blue brick.

The chamber wall to be 18 inches thick, set and pointed with cement mortar, and coped with stone ashlar dressed with bull nose inside, the top being flush with the top of filtering medium; the floor stone of setts 12 inches thick, dressed on face, set in cement grouted and pointed, laid to drain to a sump

9 inches deep, with 4-inch emptying valve communicating with the main drain.

The lower end of each main drain to discharge into a small semicircular outlet well in each filter, into which the ends of the C.I. draw off main, and the scouring pipes are to be inserted.

The outside face of the wall of each outlet well to be built of masonry of the same description as the upper part of the walls of the filters, and to be coped in a similar manner, the coping rebated to receive the C.I. cover-plates; the inside of the wall to be faced with the best white enamelled glazed radiated bricks set in cement, and backed with brindle bricks; the floor also to be paved with white enamelled glazed bricks set in and pointed with cement mortar.

The valve and weir chambers to be constructed with brindle brick faced with blue brick, and arched over with radiated blue bricks formed to the manhole boxes. Sillstones, ashlar dressed, provided with W.I., and gun-metal weir-plates attached thereto for measuring the discharge from each filter. The outlets are designed so as to maintain an absolutely steady rate of filtration, combined with simplicity of working.

In the weir chamber is to be fixed an overflow sill (or gauge plate) 3 feet 10 inches wide, with knife-edge and free overall. To insure the even working of the filter, the discharge over the sill is to be kept constant, and controlled by an approved regulator.

Overflow recesses are to be formed in the division walls of dressed masonry, set, grouted, and jointed in cement.

On the completion of each filter, and before the filtering material is put in, it is to be thoroughly tested by being filled with water up to the overflow level, and is to be maintained thoroughly water-tight.

Qualities and Tests of Materials, etc.—The stone used throughout is to be of the best qualities, of local stone and ashlar laid on its natural bed, and wetted before being used.

The bricks are to be of the best qualities, tested for absorption, and well soaked and wetted before being used.

The whole of the gravel, sand, and broken stone, before being used for concrete, is to be screened to the respective sizes specified, and well washed in sand-washing machine.

The cement is to be obtained from the best makers only, and is to be equal to, and in every respect conform to, the standard specification for cement issued by the British Standard Commission.

The cement mortar used in the masonry and brickwork is to be composed of 1 part of cement to 1½ parts of screened and washed sand, carefully measured and gauged, first dry and then with only so much water as will insure a good plastic mass.

The cement concrete used in the work is to be of two different classes, No. 1 and No. 2. No. 1 class Portland cement concrete is to be composed of the following proportions: 1 part of cement, 1 part of sand, 1 part of stone screenings, and 2 parts of broken stone (to a 2-inch gauge) or gravel, all by measure.

The whole of the sand, stone screenings, broken stone, and gravel, is to be well washed in gravel-washing machines, then thoroughly mixed by turning over four times on a wooden floor, twice dry, and twice after being wetted with clean water by a rose sprinkler; the concrete is then to be placed in the work (not allowed to be tipped from a height), and well levelled and punned.

No. 2 class Portland cement concrete is to be composed of 1 part of cement, 1 part of sand, 1 part of stone screenings, and 3 parts of broken stone (2-inch gauge), all by measure and the same qualities, and prepared in the same manner as No. 1 class.

ESTIMATE OF COST OF THREE FILTERS AS PER REPORT, BASED ON ACTUAL WORK AS CARRIED OUT IN ENGLAND.*

	£	s.	d.
Shifting soil, forming, trimming, and soiling slopes, laying grass margins, etc. (lump sum)	110	0	0
18,000 cubic yards excavation, and depositing of material, at 1s. 6d.	1,350	0	0
500 cubic yards excavation, and refilling trenches for C.I. pipes and stoneware pipes of various sizes, at 2s. 6d. ..	62	10	0
1,100 cubic yards cement concrete, No. 2 class, in the foundations and walls, at 25s.	1,375	0	0
4,814 square yards cement concrete, No. 2 class, 8 inches thick, at 5s. 6d.	1,323	17	0

* It is to be understood that in giving this specification the authors have indicated as carefully as possible the constructional details and costs of ordinary sand-filters, but without meaning to imply that they consider this method of sand-filtration to be the best.

	£	s.	d.
5,304 square yards cement concrete floor, No. 1 class, 4 inches thick, worked to a good rendered face, at 3s. 3d. ..	861	18	0
4,534 square yards special channel bricks laid dry on flat to form lateral drains on the floors of filters, at 2s. 2d.	491	4	0
330 square yards radiated brindle brick drain, 4½ inches thick, laid and pointed in cement, at 4s. 9d.	78	7	0
Header blue brick coping sides of drain set on edge of cement	30	0	0
247 square yards concrete paving, 5 inches thick, at 6s. ..	74	2	0
213 cubic yards random-coursed horizontal masonry set in cement mortar, beds and joints well dressed and squared, face to be close punched, at 50s.	532	10	0
182 cubic yards brindle brickwork in walls set in cement mortar, 9-inch and 14-inch courses, at 36s.	327	12	0
Extra on above, facing with best blue Staffordshire bricks ..	60	0	0
856 cubic feet ashlar chamfered coping set and pointed in cement, at 6s.	256	16	0
988 cubic feet ashlar chamfered coping on division walls, at 6s.	296	8	0
Inlet chamber in work as above, complete	200	0	0
Outlet valve and weir chambers in work as above, complete ..	500	0	0
Overflows	50	0	0
Estimated cost of land (not included)		nil	
6,250 cubic yards washed, screened, and sifted filtering medium as specified, laid in beds, at 7s.	2,187	10	0
1,000 cubic yards do. do. for stock (not laid), at 6s. ..	300	0	0
Preparing ground, providing sheds, hauling, cleaning out filters, and maintenance for six months after completion ..	250	0	0
Total ..	£10,717	14	0
Add for engineering and legal expenses, clerk of works, and other contingencies, 7½ per cent., say	804	0	0
	£11,521	14	0

Say £11,500 for the three filter-beds, or £3,830 for each filter, without estimating the cost of land for filter site.

METHODS OF PREPARING CRUDE WATER FOR FILTRATION.

The ordinary sand-filter is not well adapted to treat waters that are heavily charged with impurities. The deposited matter quickly blocks the pores, and the maximum "head" permissible soon fails to press through an adequate yield. Cleanings are frequent, and the filter has hardly settled down again to work satisfactorily, when it has to be thrown out of service. Increased expenses are the consequence, and a comparatively low output of filtered water.

Nor can sand-filters be expected to act with uniform efficiency if the quality of the intake is subject to large variations. Supplies taken from rivers and surface gatherings naturally vary in the charge of impurities which they convey, according

to weather and season. After heavy rains, surface waters carry far more germs, they are often discoloured with the products of decomposition, peaty acids, etc., and they are rich in suspended materials. A filter which has been working normally in fair weather will usually give poor results for some time after flood waters are discharged upon it.

Storage; Coagulation.—Hence arises the desirability of preparing the crude water in such cases for its final treatment. There are various expedients that may be resorted to—storage for a period, sedimentation with the aid of coagulants, precipitation of suspended matters by leading the water over baffles with changes of direction, and rough prefiltration.

Storage, as may be gathered from Chapter III., is an excellent antecedent to filtration; but where it is impracticable to impound three or four months' supply, sedimentation for twelve hours, more or less, with sulphate of alumina added, is a good alternative. This has been followed at Antwerp Waterworks, and a striking decrease of suspended matters results, while the water which passes on to the prefilters is of nearly uniform quality at all times. Sedimentation after this fashion is almost always employed to pave the way for the final stage of the Jewell system of purification. Probably no better means of throwing out fine silt could be suggested than precipitation with alumina. The removal of the myriads of fine particles which occur in certain river supplies has a very marked effect on the quantity of water that is dealt with between two cleanings. The germ content also decreases greatly.

The procedure at Nashville, Tenn., U.S.A., is somewhat different. The city is supplied from the Cumberland River, the water of which is frequently muddy and rich in bacteria. There is storage for three to four days' requirements in an elliptical reservoir 200 yards long and 30 feet deep. This is divided along the shorter axis of the ellipse by a cross wall. On entering the first compartment, the raw water receives a dose of 1 grain per gallon of sulphate of alumina and 0·1 grain of calcium hypochlorite. The water eventually reaches the second compartment of the reservoir in which it appears to be clear, and the reduction of the germ content averages 98 per cent.

Prefiltration.—Rough prefiltration and various modifications, embracing a succession of filterings through coarser and finer media, have lately received much attention. At Amsterdam the greatest trouble was experienced with the dune water, which carries finely-divided iron oxide in suspension, until prefilters were installed. The deposit of iron blocked the filters in a short time, more especially, too, in winter, when cleaning was frequently rendered laborious on account of the ice-sheets on the filter basins. Prefilters of coarse river gravel 3 feet thick catch the whole of the iron oxide. They have other beneficent influences. Spores and fragments of algæ are intercepted, and the bacterial content is greatly reduced. The free ammonia disappears, and the albuminoid nitrogen, as well as the dissolved organic substances, are considerably diminished. In short, the prefilters relieve the finishing-beds of more than half the work of purifying the water. The life of the latter extends to months in general, though at times it is shorter, if a luxuriant crop of algæ springs up.

The most highly developed system of successive filtration is due to MM. Puech and Chabal.* There may be as many as six stages of the treatment, beginning with coarser grades of gravel, and ending with fine sand. The consequence is that the end filter functions for six months to a year, or longer. The roughing-beds require frequent cleaning, but, as they are shallow and easily permeated by the back-current of wash-water, there is a minimum of labour required. The advantage of the Puech-Chabal system is well seen at Magdeburg, where the old filter-beds enjoyed a life of a few days only in the summer months. Puech-Chabal strainers in four steps, followed by prefilters, were interposed, and the same filter-beds as before were put in service, with the result that no cleaning was required for many months. The Elbe water, which is treated at Magdeburg, is very liable to pollution, and is frequently heavily loaded with sediment. Nevertheless, the present installation has continued to give excellent bacteriological results, the average of three of the final filtrates for the month of July, 1909, being only 13 germs per cm^3. For three months—August to October, 1909—the loss of head in the finishing-filters did not exceed 1 inch. The filters are covered, not so much for the sake of

* See *Engineering*, vol. 89, "The Treatment of Water Antecedent to Filtration," by W. Clemence. M.I.Mech.E.

inhibiting algoid growth as for the prevention of freezing during the winter, which is generally marked by a continuance of low temperatures.

Sedimentation followed by Roughing-Filters.—One of the most signal proofs of the benefit arising from a suitable preparation of the crude water is to be seen at Antwerp. There the Nethe water, always gravely polluted, is first sedimented for twelve hours with alumina, then rough-filtered through gravels after the Puech-Chabal system, and finally led to the sand-beds. The bacteriological results are taken daily, and leave no doubt as to the success of the process.

Bedford (England) furnishes an example of a novel system of treatment, for the raw water is first passed through Candy filters, and then distributed to non-submerged sand-beds by revolving sprinklers. The supply is drawn from wells near the River Ouse, and is liable to pollution from various causes. After treatment the quality is excellent.

At Bremen there is a double filtration, in case the effluent from the newly cleaned filters is unsatisfactory. The drains and valves are so arranged that the filtrate of any bed may become the feed water of another which is known to be working efficiently.

The procedure at Egham (see p. 144) is well worthy of attention, as showing how Thames water may be handled without storage, and so purified that no exception can be taken to the service water from a bacteriological point of view.

Relative Merits of the Various Systems in Use.—The relative merits of the different methods of preparing raw water for final filtration have been debated at length by various experts, and in particular by M. Cottarel, C.I., Paris, and by M. Henri Chabal. There is an essential distinction between the procedure with rapid mechanical filters and the far more prolonged and deliberate action of sand-beds. The whole cycle of operations in a mechanical filter, inclusive of cleaning, interval of suspense for the film to settle, and the period of the run, is accomplished within twelve hours on the average. Assuming, then, that samples of the filtrate have been drawn and put to a bacteriological test, and found to be unsatisfactory, the said test demanding one to two days for its performance, the condition of the filter thus proved to have been faulty is a matter

of past history. It is then too late to inquire as to the cause of defect or to attempt any rectification. The water which percolated during the run must be considered suspect, but long before any knowledge of its real character had been obtained it would probably have reached the distributing system.

The answer usually made to the foregoing argument is that the demerit is more apparent than real. Supposing that a battery of mechanical filters has passed the ordeal of preliminary tests, and nothing has transpired to show that it is incapable of treating the water satisfactorily under all conditions, then it is hardly probable that serious lapses in its action could take place unexpectedly. In any case, even if one unit of the battery were to become temporarily inefficient, the less pure water would be diluted with the better effluent of its neighbours. Flaws in the artificial film of mechanical filters managed according to regulations are simply accidents, and rare at that. Such accidents occur in sand-filters, and they are not detected until the cultures have been made from the samples. A certain volume of imperfectly purified water escapes before the tests have been completed, no matter what kind of filter is employed. A rapid filter 8 feet in diameter delivers no more than a sand-bed with a superficies of $\frac{1}{10}$ acre. A flaw in the sand-filter would probably be more extensive than any defect in the artificial film of the mechanical one. Such events are entirely within the domain of accidents, and no arguments can be adduced from them that would favour the one system rather than the other.

Without attempting to decide between these contentions, it may be said that the finishing-filter of the Puech-Chabal series, which has not been put in service after cleaning until the effluent satisfies a rigid standard of purity, seems to afford a very high degree of security against the escape of deleterious matters. The period of suspense is in many cases fifteen days, as at Paris and some other stations the cultures from the samples are examined after a longer incubation than is customary in Britain. The time allowed for these filters to mature may seem unreasonably prolonged, but it does not exceed 5 per cent. of the average life, so that it may be regarded, from the point of view of security, as time well spent. Very little water is lost, as the valves are mostly closed until the filter has ripened.

THE PUECH-CHABAL SYSTEM OF FILTRATION.

Roughing-Filters.—The attempt to simplify the filtration of muddy waters by means of double filtration is not a new device either in Britain or in America, but it was left to M. Puech to show how successive filters might be employed to the highest advantage. He passes the raw water through four roughing-filters charged with much coarser materials than are usual in the upper layers of sand-filters. The contents of these roughing-filters are also graded. The first of the series contains pebbles of the size of walnuts, the second reduces the grade to the dimensions of hazelnuts, the third to that of beans, and the fourth has granules of the size of peas. Speaking more precisely, the average dimensions of the particles in the four compartments are such that they would just pass through sieves with meshes of $\frac{3}{4}$ inch, $\frac{1}{2}$ inch, $\frac{1}{3}$ inch, $\frac{1}{5}$ inch, respectively. The depths of the layers are increased after the first, which is about 1 foot deep, while the second is 14 inches, and the third and fourth are 16 inches. These thicknesses require to be adjusted to the quality of the water, the figures given here having relation only to the water drawn from the River Seine. At stations where an installation of Puech filters is in contemplation, tests are made to find the best arrangement and the most suitable depths of the filtering materials.

Naturally, the water percolates more rapidly through the coarser grades, which it meets with first, and accordingly the superficial area of the first of the series is less than that of the second, of the second less than that of the third, and so on. The ratio of the filtering areas is approximately 1 : 1·5 : 2·5 : 5. The speed of filtration is inversely proportional to the area over which the current is spread, and consequently it slackens down in passing from one roughing-filter to the next. In the last the water percolates at one fifth of the rate at which it passes through the bed of large particles in the first (Fig. 23).

Prefilters.—In sequence to these four *dégrossisseurs*, as they are called, comes a prefilter, with a superficies enlarged to two and a half times that of the preceding bed. The prefilter resembles very much an ordinary sand-filter, the elements from below upwards being first a floor of perforated bricks,

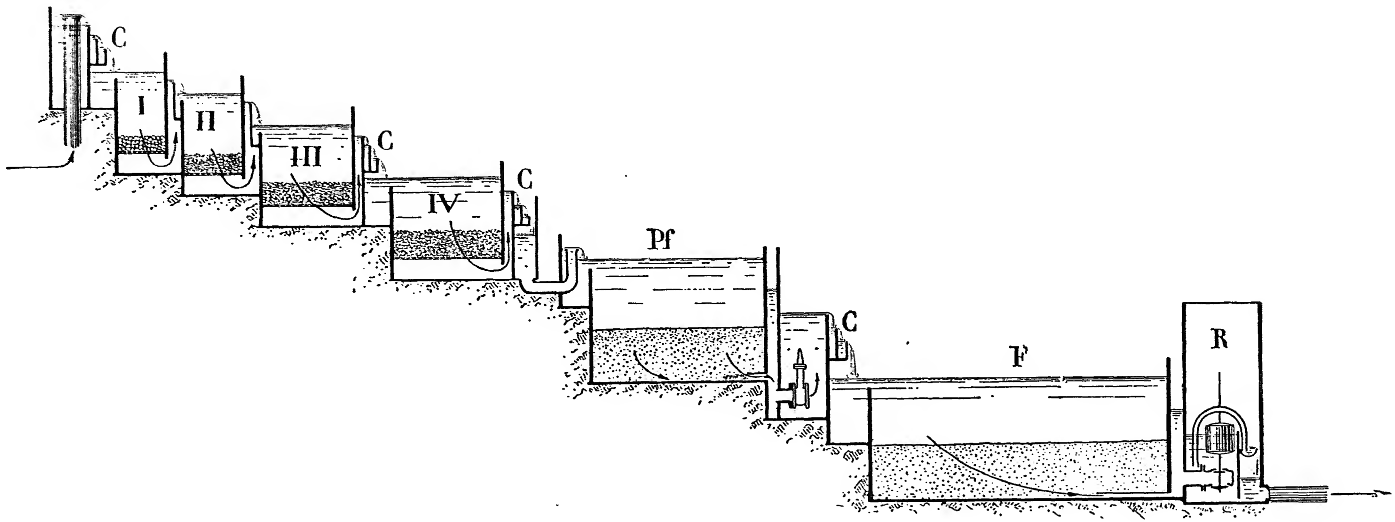


Fig. 23.—Diagrammatic Section of Puech-Chabal System.

I.-IV., dégrossisseurs ; C, cascades ; Pf, prefilter ; R, siphon regulator (Didelon) ; F, finishing filter.

then a foot of gravel of the same grade as that of the fourth *dégrossisseur*, and above these 2 feet of sand of medium to coarse grade, with granules averaging $\frac{1}{8}$ inch in diameter. With a head of 3 feet, the water passes through the prefilter at four or five times the rate which is usual in slow sand-filters. By the time the Seine water has traversed the *dégrossisseurs*, it has parted with the greater portion of its suspended impurities, so that the life of the prefilter is comparatively a long one. On the surface a film of algoid growths is formed, and the bacteriological purification which was begun in the roughing-filters is here more searching, and the number of germs is much reduced. The arrangement of the sections of the Puech installation already described will be made clear by the diagram on p. 135.

The Finishing-Filter.—Having now submitted to five consecutive filtrations, the nearly purified water is led to the finishing-filter (Fig. 23). The area of this greatly exceeds that of the prefilter, and the speed of percolation is limited to 2 gallons per square foot per hour as a maximum (downward flow of 4 inches per hour). The composition of the finishing-filter is of the pattern of the ordinary sand-filter. Perforated bricks form the substratum, and on these lies a bed of small pebbles, then a layer of gravel, and over all 2 feet of fine sand. The total depth of all these materials is 4 feet.

The finishing-filter requires no scraping or cleaning for long periods. It would seem to be the purpose of the inventor of this system to so perfect his arrangements that no cleaning will be required. Sufficient vegetable matter is not left in the incoming water to give rise to a *couche* of algæ, but vegetable life of some species flourishes in the waters of the finishing-filter—at any rate during the summer months. The water overlying the sand at times contains growths floating at the surface or within a foot of it. In his communication to the Association of Water Engineers, 1907, Mr. Devonshire, referring to this, explains that the seeming growth is actually composed of decaying vegetable matter. M. Chabal avers that algæ from the lower parts become detached, and rise to the top. A scum or loose agglomeration of vegetable forms collects, and this requires to be lifted out from time to time during the warmer months.

The Finishing-Filter should be covered.—M. Puech (Trans. Mech. Engin., 1909) affirms that in his view the finishing-filter should be covered in order to prevent the appearance of vegetable growths. In fact, the effluent from uncovered finishing-filters, when viewed in a colour tube or turbidimeter, is occasionally seen to be less transparent than the inflow from the prefilter. This may be accounted for by discoloration from the decaying matters overlying the sand-bed in the last stage of the process. But that the finishing-filter serves a good purpose there is no reason to doubt. It completes the bacterial purification, and confers a remarkable uniformity on the results obtained.

In other cases where the Puech system has been adopted, it is worthy of notice that modifications have not infrequently been introduced. At Waelham, whence water is drawn from the River Nethe for the Antwerp supply, there are three groups of gravel-strainers, but no prefilter. Moreover, the strainers are covered to exclude light and prevent vegetable activity. The finishing-filters are left to accomplish their full share of the work. The life of the finishing-filters is much extended. The bacteriological purification is completed in them, as the works manager, Dr. Kemna, thinks it should be.

Dr. Kemna states that the roughing-filters have much to recommend them when applied to the purification of river water. Most of the suspended matters are arrested. This would seem to be the conclusion come to by the municipal authorities at Paris, for since the Council adopted the Puech method of purification in 1904, no more settling reservoirs have been constructed at Paris (Trans. Inst. Mech. Eng., 1909). Dr. Kemna further finds that about 90 per cent. of the microbe content of the raw water is held back by the *dégrossisseurs*. This is the figure at Suresnes, and at Nantes and Cherbourg it is somewhat lower.

As no film is formed upon the gravel-strainers, it is of interest to consider how so large a percentage of the germs is trapped in them. This point has been discussed by Dr. Kemna (Trans. Assoc. of Water Engineers, 1907; see also p. 86). It must be admitted that it is not for want of openings large enough that the particles of mud and the germs fail to pass through. It is not a case of the interstices being too narrow.

Elsewhere we have discussed the biochemical action of the

filter-bed. The retention of organic matters and the absorption of colloids goes on in Puech's strainers, and, according to Dunbar's investigations, there is a decided advantage in having the filtration done by instalments. This does not arise to any great extent from the better retention of the sediment, seeing that probably as much of the mud could be arrested in one bed of sufficient thickness as in three or four filters in tandem. The advantage appears when we consider the chemical action of sand straining on organic matters, particularly colloidal solutions. Dunbar has shown, in connection with these, that from a 1 per cent. solution a single filtration through sand cannot remove more than half. But if the filtrate be again run through a sand-filter, a very large part of the remaining colloids disappear. No potable waters, of course, contain anything like 1 per cent. of, say, albuminoid ammonia, but the same principle would seem to apply to waters contaminated with minute quantities of sewage matters. As Dr. Kemna remarks: "The first treatment does things by halves; the subsequent one deals the final blow."

Aeration during Treatment.—It will be observed from the diagrammatic view of the Puech-Chabal process in Fig. 23 that aeration of the water is promoted by cascading from compartment to compartment. The usual effects of aeration follow, and with certain waters this would doubtless aid the purification materially. But in order to form cascades the filters must be placed on sloping ground, and this, together with the loss of head, may give rise to difficulties. Therefore it is to be mentioned that the cascading is dispensed with if need be.

In the tabular statement at p. 356 will be found details of the capital outlay and maintenance charges so far as concerns the Puech installation. The following analyses illustrate the work accomplished by the process:

TABLE IX.

AVERAGE NUMBER OF MICROBE COLONIES, AND PERCENTAGE REMOVED.

River Water.	From Puech Strainers.	Prefilter.	Finishing-Filter.
38,000	3,000—*i.e.*, 92 per cent.—removed	680—*i.e.*, 98 per cent.	93—*i.e.*, 99·8 per cent.—removed
6,000	610—*i.e.*, 90 per cent.—removed	105—*i.e.*, 98 per cent.	29—*i.e.*, 99·5 per cent.—removed

While the finishing-filter operates for lengthened periods without fouling or clogging, the prefilters are emptied about once a month, and the top layer pared away. The *dégrossisseurs* are cleaned weekly, or more frequently if the water is unusually turbid.

Uniformity of the Bacteriological and Chemical Results.—A point worth noticing in connection with these filters is the constancy of the results as shown by the frequent and periodical

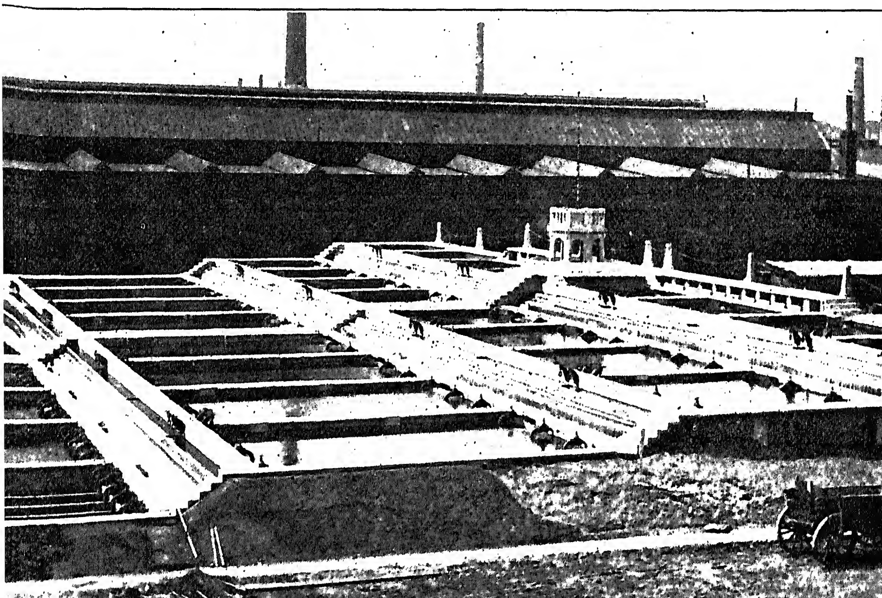


FIG. 24.—PUECH-CHABAL SYSTEM AT MAGDEBURG.

analyses. M. Puech attributes this to the arrangement by which a definite fraction of the whole installation is always at work, while the remaining part is undergoing cleansing (Fig. 24). At Suresnes-Nanterre, the roughing-filters are four in number, and each is divided into four compartments. Of these compartments, only one is out of action at a time, so that fifteen-sixteenths of the whole battery is continually operative. Nor is the work of cleaning the *dégrossisseurs* by any means troublesome. As the gravels are only 12 to 16 inches deep, they are quickly cleaned by a jet of water, while the materials

are turned over. Compressed air has also been tried, with the best results. At Magdeburg, the air under pressure is introduced below the perforated bricks on which the gravels rest, and a small quantity of unfiltered water is kept running as the cleaning proceeds. The filtering materials are greatly agitated. The slime detaches quickly, and is carried away by a drain at one corner of the bed. The colour of the wash-water changes from dark brown or chocolate to creamy-white at the end of the cleansing, which occupies from five to ten minutes.

The rate of filtration in the end filter is regulated by an automatic device described at p. 105.

Puech-Chabal filters are now at work in several important places, as Cherbourg, Ismailia, Valence, Nancy, and the installations completed at Magdeburg and Waelhem further enhance the reputation of the system.

The Puech system has been imitated by American engineers for the supply of Bethlehem, U.S.A., except that the "scrubbers" all lie in one bed. The succession of materials is as follows: First is a layer of 3-inch pebbles, about 9 inches deep; then 9 inches of coke egg-size, and over this 24 inches of coke walnut-size. These materials are laid between partitions of slate set parallel. Each partition is four slates deep, and each row of slate lies at an angle to the next, so as to cause the water to find its way through the filter-bed zigzagging. A layer of sponge 18 inches thick is spread over the top of this scrubber. The finishing-filter does not differ materially from the slow sand arrangement. So thorough is the work done by the scrubber that the end filter can operate to advantage for three months between cleanings. On the average the speed of filtration is high, as much as 200 gallons per square foot per day being accounted for. To save time in filming after washing, the scum from the top of the scrubbers is transferred to the water in the finishing-filter. The water is not suitable for coagulant treatment owing to its softness. An artificial film has been spoken of, but nothing satisfactory has as yet been hit upon. The results of the purification at Bethlehem are stated to be good from a bacteriological point of view.

THE ANDERSON SYSTEM.

This system is of interest chiefly on account of its cheapness and reliability, and also because of the important place assigned

to it in the Paris Waterworks. The coagulant employed is oxide of iron, and this precipitant is introduced into the water by aid of a rotating cylinder in which the raw water, air, and scrap iron, are brought into mutual contact. The cylinder is made to revolve on trunnions by a gearing (H, Fig. 25), and as it turns the water to be purified travels slowly along, entering by conduit E, and going from right to left as illustrated. The rotating cylinder lifts up the broken scrap iron lying within by means of the curved beakers seen in section at D. The fragments of iron gradually pass into solution, and the continual agitation and friction keep the metallic surface bright and clear. In Mr. Anderson's experimental apparatus the iron cylinder was 6 feet long and 4½ feet in diameter, and it was charged with about ½ ton of scrap. The rotational speed was twenty turns per hour. With an inflow of 166 gallons per minute, the water had contact with the iron fragments for three and a half minutes, and in that brief interval it carried away in solution 0·1 to 0·2 grain of iron per gallon.

This small quantity of iron was found to be sufficient to serve all the purposes of a coagulant. By aeration the ferrous salt first formed is converted into ferric, which separates as a precipitate, and in falling carries with it the fine silt and other impurities. The aeration may be effected by cascading the effluent from the "revolvers," as is done at Paris (Choisy-le-Roi), or by forcing a blast of air through perforations in the false bottom of the efferent conduit. The latter plan was formerly adopted at Antwerp, where the revolving purifiers, 15 feet long and 5 feet across, were able to deal with 600,000 gallons each per day. The experience gained at Antwerp shows that the efficiency of these purifiers is dependent very much on the state of the raw water. Mr. Devonshire describes their usefulness as "spasmodic," owing to the marked variations in the composition of the crude Nethe water with which the reservoirs are filled.

On the other hand, the Paris water is always capable of satisfactory treatment in this way. The high degree of hardness would seem to favour the ready formation of proto-salts of iron. At Antwerp this chemical change at times hangs fire, so that the revolvers had to be put out of action until conditions became more favourable.

To obviate this inconvenience, advantage may be taken of

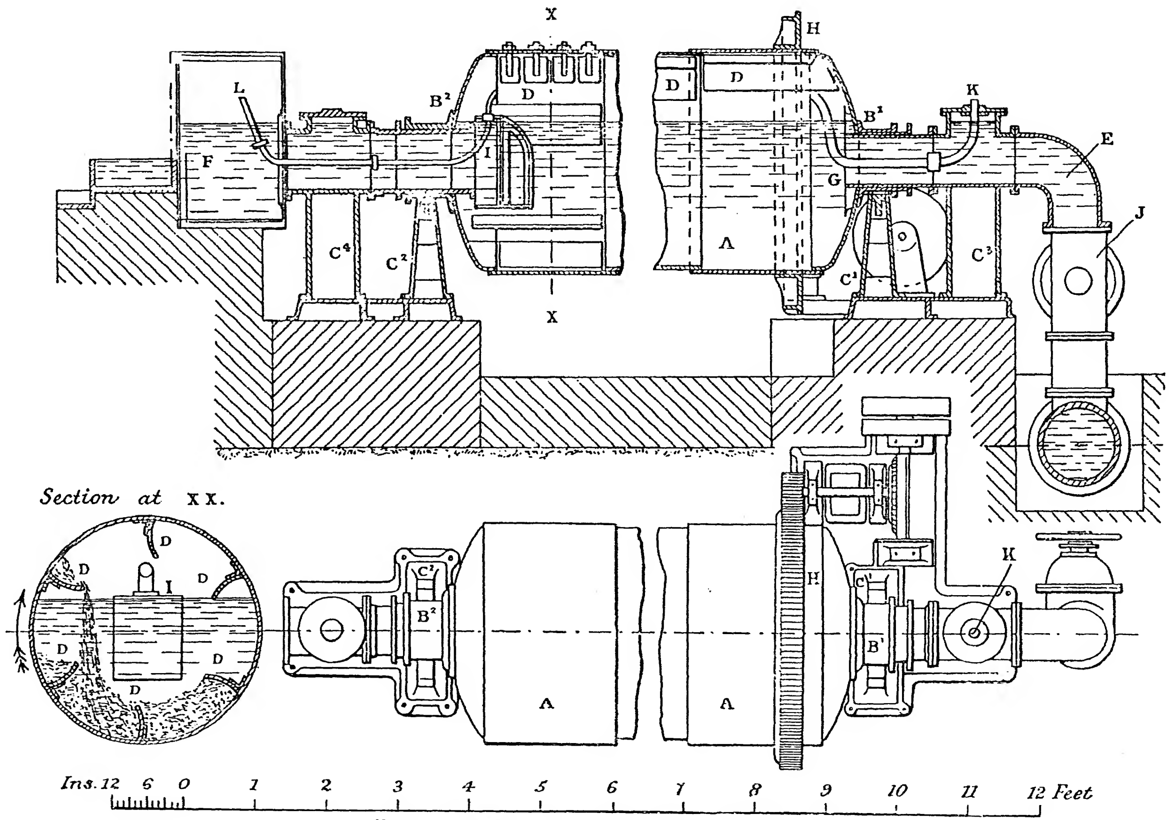


FIG. 25.—ANDERSON REVOLVING CYLINDER.

A, rotating cylinder; B^1 B^2, bearings for hollow trunnions; C^1 C^2, cylinder supports; C^3, support of inlet pipe; C^4, support of outlet pipe; D D, curved beakers; E, inlet pipe; F, outlet pipe; G, distributing pipe; H, gear wheel; I, outlet cover; J, valve; K, air inlet; L, air outlet.

the fact that the introduction of ferric oxide in sufficient quantity into the crude water exercises a most desirable influence on its purification in the sand-bed. In that case the water does not go through the cylinders, but is led into a tank, and caused to travel upwards and downwards in contact with iron plates, which are kept in an active state of rusting with the help of air-jets suitably arranged. Important results may be anticipated from this variation of the Anderson method.

When the precipitate of ferric oxide takes place, there ensues a coagulation of the colloidal ingredients, and suspended matters are entangled and carried downwards. At the Paris Waterworks the outflow from the cylinders is led into the decanting tanks, which are described at p. 50. Arrived at the sand-filters, the iron and colloidal substances still remaining in suspension go to form a felting which arrests a high percentage of the bacteria. In fact, the really active layer of the bed, for some time after cleaning at least, is the deposit of colloidal bodies, fine silt, and organic matters.

The sand-filters rest on sloping floors, inclining towards a diagonal of the bed, along which runs the leading drain. Side-weepers gather in the tiny rills. All the drains are of brick, and the rest of the floor is covered with flint pebbles, kidney-size. Over these is a stratum of smaller pebbles, then gravel and fine sand. The depth of all these layers is 26 inches (Trans. Water Engin., 1907, p. 213).

The speed regulation is controlled by hand, and the average percolation is 8 inches per hour, the head being 3 feet. The bacteriological analysis indicate superior efficiency. Table X. gives the average results for two years. Weekly analyses are made, and samples are also drawn at other times when additional tests would seem to be desirable.

TABLE X.

NUMBER OF COLONIES PER CM^3. AFTER FIFTEEN DAYS' INCUBATION.

	Seine Water.		Marne Water.	
	Crude.	Filtered.	Crude.	Filtered.
In 1905	133,729	310	63,389	300
In 1906	177,716	843	95,517	151

It does not follow that the filtrate is free from pathogenic germs, and, in recognition of the importance of this circumstance, it is now the rule that the effluent must not carry *B. coli* (see p. 288). It is presumptive evidence in favour of the Anderson process that fatal cases of typhoid in the area supplied by the installation have been decreasing, from 0·07 per 1,000 to 0·05 per 1,000 in two years.

The cleaning of the filters, which run on the average for a month, is carried out by lowering the level of the water to a depth of 2 or 3 inches below the top of the sand. Men walking on wide boards and using special scrapers clean off the dirty layer. The filter is then put into communication with a neighbouring one from below, so as to raise the level of the water once more. After this the filter receives a filling of water from the revolvers direct, carrying the full load of iron salts. But it is never put into service immediately after cleansing, and that precaution usually means the stoppage of the filter for twenty-four hours. The effluent is drawn from the newly cleaned bed after filming with the precipitation from the heavily-laden water. Even then it is drawn cautiously, and the first portion is allowed to run to waste.

South-West Suburban Company, Egham Works.—There can be no better test of the efficiency of a purification plant than calling upon it to furnish drinking water, uniformly of good quality, from such a river as the Thames in its lower reaches. So far as analytical results show, the Egham works fulfil their purpose in a very satisfactory manner, and this they do without the aid of storage or a period of sedimentation in quiescence.

The raw water is prefiltered, according to the Howard system, in four stages, and afterwards treated on finishing-beds of fine sand artificially filmed as hereafter to be described. The direction of the current in the prefilters is from below upwards, and the method of construction adopted allows the crude river water to deposit much of its grosser impurities in the underlying subsidence chambers (Fig. 26) as it travels onwards. The richest deposit is found in the first chamber, but some part of the sediment accumulates in the others. These are easily cleaned by washing into a drain which is brought to the basement, and by an arrangement of sluices any one chamber may be thrown out of working without disturbing

the others or interrupting the filtration. The material used in the first two prefilters is coarse gravel or shingle, while in the third and fourth is a bed of polarite. In the fourth prefilter the grade of polarite is finer than in the third. Washing these filters is a simple process, for it is only necessary to turn over the gravels or the polarite with shovels, beginning at one side, and laying the perforated bottom bare. With the help of a jet of water the adherent mud and slime is washed through the perforations into the chamber underneath. By throwing back the washed material, more and more of the dirty layer is exposed until the whole has been gone over. The diagram will make clear the relation of the various parts of the structure and the direction of the flow.

The finishing-filter would naturally in time take on a film of algæ sooner or later after being cleaned or scraped, but, in order that no time may be lost in getting a cleaned bed into play, the water which is first brought on to the filter is treated with a solution of sulphate of alumina. This is distributed under pressure over the bed by means of a hose-pipe from a patent mixing apparatus. In the course of an hour or two the alumina has become deposited into a thin, compact sheet which excludes bacteria as perfectly as an algoid film. The first runnings of the freshly filmed bed are taken at a very low head, which is cautiously increased. This system* is that of the Bacterial Water Purification Co., Westminster, who own the Howard prefilter patents.

SAND-FILTERS NON-SUBMERGED.

M. Baudet, in his publication "Filtres à Sable Non-submergé," has adduced strong arguments in favour of this description of filter. He first takes pains to point out the defects of the ordinary type of sand-filter, emphasizing the fact that the removal of 99 per cent. of the micro-organisms from a water rich in bacteria may yet leave tens and hundreds per cm^3., some of which may well be pathogenic. He has grounds for believing that the non-submerged filter is capable of giving an effluent practically free from germs of all kinds. The possibility of purifying river water by sprinkling over sandy

* To the engineer in charge, Mr. D. Rankine, the authors are indebted for permission to inspect this highly interesting system.

strata has occupied the minds of certain French engineers for many years. M. Janet proposed to distribute the water of the Oise upon the gravelly hummock of Montmorency, which rests on impervious formations, and subsequently collect the effluent by a circular drain. This project was not carried out, but Dr. Miquel constructed an experimental filter with a surface of 16 square feet and a depth of 3 to 4 feet of fine sand. The incoming water was sprinkled over the surface by a network of fine jets. Dr. Miquel devoted his attention chiefly to the effect of this experimental filter upon the colonies of *B. coli*, with which the raw water was regularly infected.

Action of Dr. Miquel's Filter on Bacteria.—At the outset the filter was unable to arrest bacteria; they passed through freely. A month elapsed before the sand was able to reduce the numbers to 10 per cent. of the original. Already, however, the *B. coli* had disappeared from the effluent, careful cultures maintained for fifteen days showing no trace of it. Many months elapsed before the reduction of bacteria of all sorts reached 99 per cent., but in the seventieth week of continuous operation it was found that only four colonies survived out of several thousands in the raw water. From the third week up to the fortieth no *B. coli* were discovered in comparatively large samples of the filtrate. The top layer was scraped and washed soon after, and during the next fortnight very extensive researches led to the detection of two specimens of *B. coli*. From the forty-ninth to the eighty-fifth week no single germ of this class passed the filter.

A large number of experiments were then made with bacilli characteristic of putrefaction, with *B. typhosus*, etc., but no single germ of the kind escaped.

M. Baudet's Improvements.—M. Baudet followed up these investigations. He constructed a filter on a much larger scale than Dr. Miquel's, with a surface of 175 square feet and 4 feet of fine sand. The sprinklers were formed by fine jets, twenty to the square yard or thereby, while the rate of filtration was regulated to 4 inches per hour.

The crude water applied to this filter proceeded from an underground source in the Valley of the Loire. The country does not lend itself to furnishing sound drinking water, for the chalk near the surface is much broken and fissured, so

that impurities reach without difficulty the impervious layer which throws out the spring water. This contains in general a thousand germs per cm^3., and among these *B. coli* and bacilli of putrefaction. This is hardly to be wondered at, for the land all round is tenanted, and there are numerous cesspools, whose contents are at liberty to percolate through the chalk.

M. Baudet's filter surpassed expectations. It ripened to the full perfection of its working in a few days. Samples of the filtrate were submitted to the Laboratoire Supérieur d'Hygiène de France from week to week for six months, and never once were any objectionable bacteria found. The number of other species which were able to show on the gelatine after fifteen days' culture was always small—three on the average, and six as a maximum.

Influence of the Grade of Sand and of Slow Filtration.—M. Baudet attributes his success largely to the slowness of the filtration. In fact, with the fine grade of sand which he employed, it would have been difficult to increase the rate without submerging the sand. Dr. Miquel had permitted a higher speed, and, though at the time when his filter was working best no *B. coli* passed, the total number of germs was occasionally three times as great as with M. Baudet's apparatus. When the rate of filtration was increased to 12 inches or more per hour, *B. coli* made their appearance in the effluent, and they continued to do so for a time, though the rate was reduced.

M. Baudet ventures an explanation. When the water is pressed through the filter at high velocity, it establishes fine canals, which carry the bacteria lower and lower down into the sand. Also the water flows more readily in these fine passages than among the compacted granules, and thus has a tendency to sweep out the germs. This accords with Pennink's views on the effect of variations of speed.

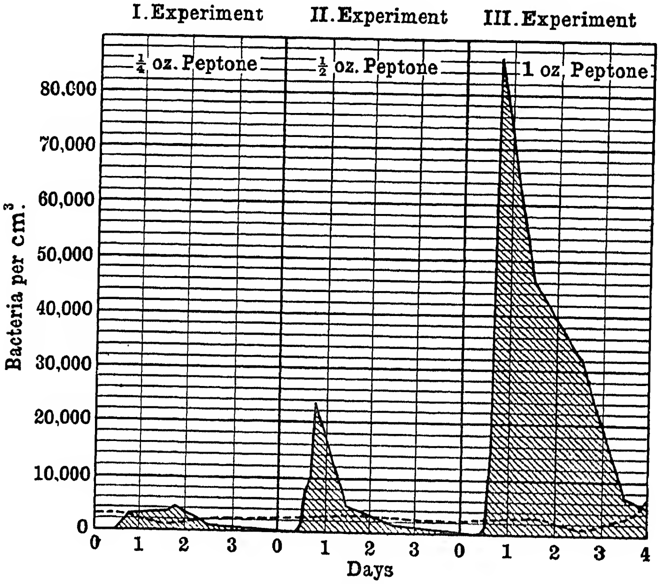
If we refer to the tables showing the analyses of the filtrates from M. Baudet's installation, we shall find that there is no relation or proportion between the number of bacteria in the crude water and that found in the samples of the effluent examined. For example, with 300 per cm^3. in the raw water, the figure for the effluent was 3; with 1,100 in the former, it was 2 in the latter; with 1,000 in the crude, it was 4 in the puri-

fied water. Looking at this peculiar circumstance, M. Baudet concludes that here we are not really dealing with a case of sifting out so many of the germs which enter, and letting one here and there escape. Were that so, there would be some relation between the total number which occur in the raw water and the number which find means to escape. He therefore argues that all the germs in the incoming water are caught by the sand, while those which are dispersed through the filtrate are derived from the underdrains. M. Miquel agrees with this opinion, and he regards the bacteria which do escape as exceptional.

One circumstance which would support this contention is that the number of bacteria in the filtrate does not augment when the rate of percolation is increased—of course within limits. When Dr. Miquel raised the speed from 4 inches per hour to 5, 6, and 7 inches, the number of germs decreased from about a dozen to three or four. There should have been a contrary result if there existed between the number of germs in the incoming and outgoing water a relation that would almost necessarily be affected by the duration of contact of the filtrate with the sand.

Effect of adding Solutions of Organic Matter to the Raw Water.—In order to bring about an increment in the number of bacteria in the effluent, it does not serve to infect the raw water with large doses of prepared cultures. Another way must be taken. Let a small quantity of nutrient fluid be mixed with the inflow, and the germ content filtrate very soon responds. Dr. Miquel scattered over the surface of the sand a solution of $\frac{1}{4}$ ounce of sterile peptone, and in the course of a day the number of bacteria in the filtrate rose to 3,000 per cm^3. On repeating the experiment with $\frac{1}{2}$ ounce of peptone, some 20,000 germs per cm^3. were in evidence, and larger doses of the nutrient liquid still further raised the pullulation. In Fig. 27 there is exhibited graphically the results of Dr. Miquel's experiments. The broken line shows the number of bacteria in the crude water, and the shaded area indicates the number in the effluent after the application of the quantities of peptone specified for each test. The figures below refer to days, those at the left-hand side to the number of colonies per cm^3. in the filtrate.

M. Baudet claims the superiority of his non-submerged filters over the common form on various grounds. He imagines that the sand does not ally itself so closely to the walls of the common filter-bed that it can prevent a creeping downwards of imperfectly purified water when there is pressure brought to bear at the surface. With a non-submerged arrangement there is practically no pressure, he finds, on the side-walls. A hole bored in the wall does not allow any escape of the water



Dotted Line.=Number of Bacteria in Raw Water.
Shaded Area.=Number of Bacteria in Filtered Water.

FIG. 27.—GRAPH SHOWING DR. MIQUEL'S RESULTS.

in the bed. In the matter of aeration the advantage would seem to be on the side of M. Baudet's apparatus, for the water, as it sinks into the sand, carries air with it constantly, so that the filtrate is found to have a large percentage of dissolved oxygen.

As the non-submerged filters may be under roof, there is no trouble with algoid growths, nor with any effects of their decay, such as bad odours or discoloration of the water.

The Conseil Supérieur d'Hygiène de France has interested

itself in M. Baudet's researches, and has so far approved of his scheme that it authorized an installation of non-submerged filters at Châteaudun with a filtering superficies of 300 square yards. The sand used is of fine grade. Sixty per cent. of the granules are less than $\frac{1}{30}$ inch in diameter, and the average of the remainder is $\frac{1}{20}$ inch. There are sixteen jets per square yard to distribute the raw water, and the rate of filtration is regulated to $6\frac{1}{2}$ inches per hour. It is likely that the grade of sand may be still further reduced, but meantime the filtrate is reported to be bacteriologically pure. The crude water at Châteaudun is clear, and it carries very little sediment. M. Baudet considers that turbid waters would require pre-filtration before being treated on the non-submerged system. A diagram of the installation at Châteaudun is given in Fig. 28. It is constructed of armoured concrete.

COAGULANTS.

There are two chief purposes which coagulants serve in the process of water purification. In the first place, they greatly accelerate the deposition of fine silt and earthy matters, so finely divided that they are ordinarily held in suspension by stagnant water for hours, and even days. In addition, the coagulant serves to film the filter, and this it can do in a very short time, probably in fifteen minutes or half an hour.

These advantages accruing from the use of coagulants have made rapid filtration possible. Through a sand-bed filmed in the approved way with coagulated matters, water may be allowed to travel a hundred times more rapidly than it does in general in the slow sand-filter, and the elimination of impurities will be none the less successful. In the course of a year many days are saved in doing away with the period of suspense between the cleansing of a bed and the time when it is sufficiently filmed with algoid growths. This period usually mounts up to a week or more after each cleaning; and though it is not the practice in this country to wait until the natural film has grown, it is quite contrary to good management not to do so.

The waters of many rivers bear along with them a sediment so impalpable that it passes through the ordinary sand-bed in

the same way as precipitated sulphur slips through blotting-paper. Sand-filters would not remove the finer part of the suspended matters from the supplies drawn from the Nile, the Hooghly, or the Mississippi. But if a few drops of a solution of coagulant be added to a test-glass of muddy water, there ensues a clearing and a transparency in a few minutes. Water which has been made turbid by rubbing into it some moulder's clay will remain cloudy for twenty-four hours at least. But the addition of a solution of alum or alumino-ferric produces a wonderful change. In a few minutes the cloudiness will disappear from the top stratum, and gradually all visible sediment will be carried to the bottom.

It is to be noted that sulphate of alumina must undergo a chemical transformation in the water before it develops its coagulating potency. Provided that there is carbonate of lime or magnesia in solution, the following reaction takes place :

$$Al_2(SO_4)_3 + 3CaCO_3 + 3H_2O = Al_2(OH)_6 + 3CaSO_4 + 3CO_2.$$

Most natural supplies contain sufficient carbonate of the above-named alkaline earths to equate chemically with the sulphate of alumina. But if there be a deficiency, as may occur with waters from peaty gathering grounds, a suitable proportion of lime-water, or milk of lime, or chalk, may be applied to the water.

In ordinary circumstances, 1 grain of the coagulant suffices for a gallon, but the proper amount to add depends entirely upon the nature of the raw water. Experiments must be made to find out the amount which will perform the work to the best advantage under the given conditions, taking also the time allowed for the reaction into account.

At Alexandria the period of sedimentation is extended to six hours, and at various places in America from one to five hours is so permitted in the settling tanks. On the other hand, the British-made mechanical filters are commonly worked without previous sedimentation, and the solution of sulphate of alumina is introduced into the raw water just as it enters the filtering drum.

Advantage of Sedimentation after Coagulation.—There are manifest advantages in preparing the water, by a period of sedimentation, for treatment in the filter after adding coagulant.

In the first place, the solution of the substance added is able to diffuse through the whole volume, and the reaction, which, with these dilute solutions, is not by any means instantaneous, has time to complete itself. There is less risk of any portion of the coagulant passing away unchanged into the effluent. Moreover, the separation of the greater portion of the suspended impurities serves to prolong the life of the filter. In general, some part of the coagulant and silt is carried to the filter, and

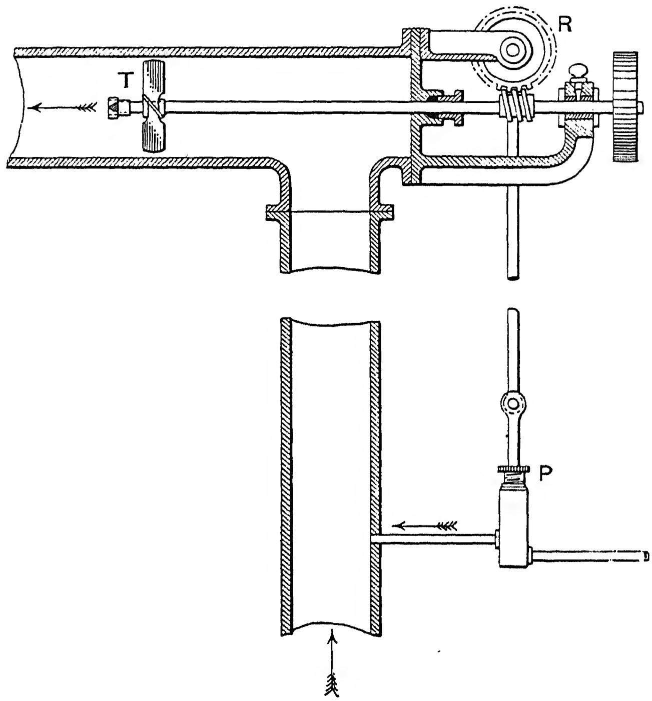


FIG. 29.—TURBINE COAGULANT FEED.

intentionally so, the object being to film the sand-bed. In order to accelerate this operation, the supply first admitted to the filter after cleansing may be taken directly from where the coagulant is introduced, without any period of sedimentation intervening.

In the same way, those installations that have no settling tanks are so arranged that the dose of alumina may be increased for a short time after the run has commenced.

Mode of applying the Coagulant.—The introduction of the coagulant to the raw water in a judicious way when the filters are joined up to the mains is a matter of no little importance, and of late experiments have been made by Messrs. Bell Bros., Ltd., Messrs. Mather and Platt, Ltd., and other manufacturers of filters, to find the best method of operating. The coagulant, let it be remembered, enters a pipe in which the crude water is moving at, say, 25 feet per minute. A jet of the solution of sulphate of alumina forced into the pipe 25 feet in front of the filter will thus have one minute to intermingle with the main stream. In such limited time and distance it is well known that a very partial mixing only can be expected. Further mingling occurs in the dome of the filter, but there is no certainty that all parts of the crude water are reached by the coagulant, or that the chemical reaction is well dispersed through the volume.

What militates against complete intermingling is the circumstance that the coagulant is contained in a comparative small volume of water. The less the bulk of the precipitant, the greater will be the difficulty of distributing it. To mix fluids in a vessel, we must stir, or invert several times, or shake. As the two last methods are inapplicable here, an attempt at stirring can be made by placing a turbine in the main. The diagram (Fig. 29) will make the plan apparent.

The turbine serves another very useful purpose. Its rate of turning depends on the flow, and its motion is communicated to the small pump which injects the coagulant by way of the pipe (A). Thus, the dose of the precipitant is made to depend upon the rate of flow in the main. This is as it should be.

The Harris-Anderson Automatic Distributor and Solutioner.—There are two main principles involved in the automatic delivery of coagulant in the Harris-Anderson Purifier, the first being the diverting of a constant small fraction of the incoming water, while the second relates to converting the separated portion into a solution of definite strength and re-introducing it into the raw water.

To divert a fraction of the supply, say 2 per cent., the apparatus shown in Fig. 30 is employed. The whole stream falls upon the turbine, which rotates and discharges into an annular trough divided into three compartments. The larger

one takes up 98 per cent. (or any other fraction) of the whole circumference, while each of the small compartments seen to the right of the diagram occupies in this case one-hundredth part of the whole round. These two compartments are intended to provide for two different solutions, as lime water and

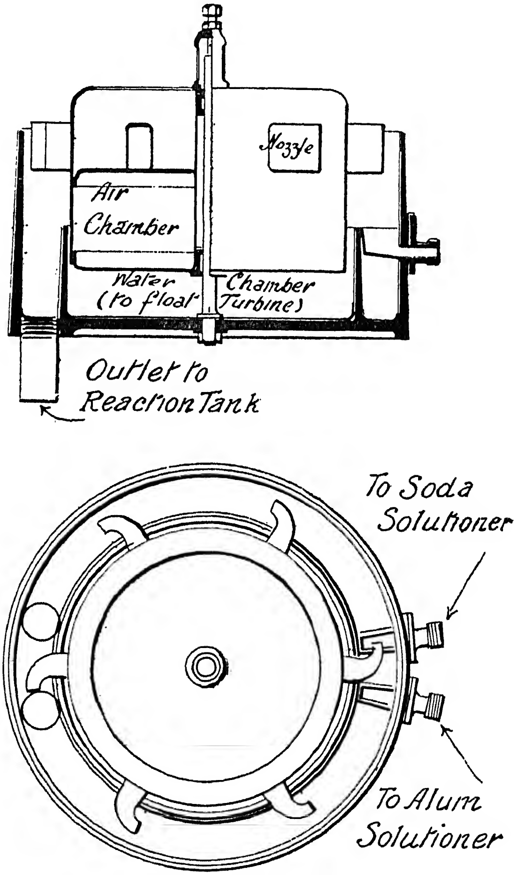


FIG. 30.—HARRIS-ANDERSON DISTRIBUTOR.

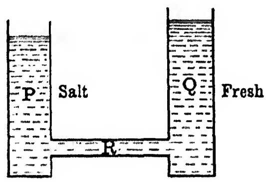
soda. But supply for one, two, or more solutions in any proportion required can easily be arranged for. The outlet pipes lead to two "solutioners" of the design shown in Fig. 31.

It is known that if two vertical tubes, P, Q, containing liquids of different densities, say fresh water and salt water,

be put into communication, as by the cross-piece R, the liquid columns will at once assume a position of balance. The denser fluid will stand a little lower than the other, because a slightly longer column of the specifically lighter liquid is required to establish equilibrium. On this principle depends the action and the constancy of the solutioner.

There are three cylindrical tubes, B, C, D (Fig. 31), within the outer vessel A. Of these B and D are fixed, and C can be raised or lowered at will by a screw adjustment. Provision is made to allow free communication between the annular chambers below.

The substance to be dissolved is put into the wire cage shown, and is lowered into D, where it gradually passes into solution, and the denser liquid descends and flows into the annular space bounded externally by C. Here it mingles with a current of raw water which arrives from the distributor and enters between C and D. This current sweeps the solution along with it into the outermost annular space, of which A is the external boundary, and so carries it on to the outlet.



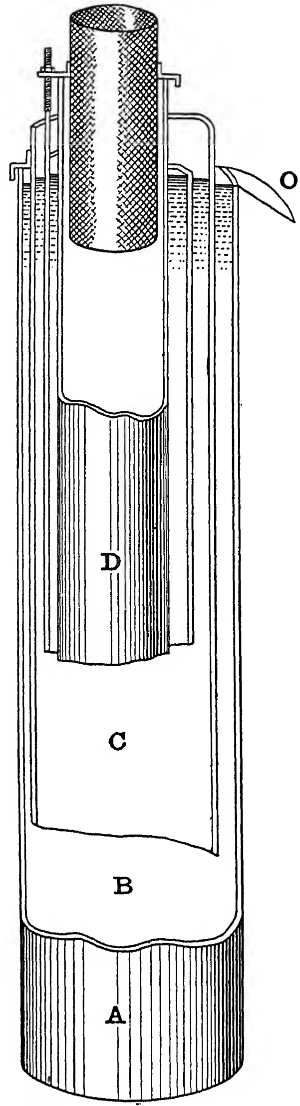


FIG. 31.—HARRIS-ANDERSON SOLUTIONER.

We have not yet explained the function of the annular space between B and C, but, as will be seen presently, this

plays an important rôle in maintaining the constancy of the strength of the solution which leaves the solutioner.

As the liquid in the outermost annular chamber is denser than the raw water, it is clear that equilibrium between the columns demands that the fresh-water level between C and D shall be higher than that of the outflow at O. The greater the difference of level between these two, the denser will be the solution. The height of the cylinder C is adjusted to assure a certain strength of solution previously decided upon. Now, if too much of the substance enclosed in D be passing into solution, the level in the space between C and D naturally tends to rise. Consequently there is an overflow into the next annular compartment between B and C, which dilutes the outgoing current by forcing water out from below B. This reduces the density of the solution in the outermost compartment, and by lightening that side of the balance lowers the level at the inlet to normal height. The arrangement is therefore automatic. It is also adjustable for delivering any strength of solution by the mere turning of a thumbscrew. And, as we have seen, the volume of solution added is a constant fraction of the total volume of water in the supply.

Mannock and Sibley's Patent Injector (made by Mannock, Sibley and Co., London).—The simple and effective apparatus here illustrated automatically regulates the quantity of chemical introduced by its operation, no other mechanism being employed than a Venturi tube and a couple of pistons, with the necessary connections. The difference of pressure between the throat and upstream end of the Venturi tube applied to the piston suffices to inject the chemical (Fig. 32).

The upstream end of the Venturi tube is connected to the lower end of the cylinder, as represented in the diagram. On the connecting tube is a three-way cock, which is automatically turned by tappet gear at the beginning and the end of each stroke. It admits the water from the main when the piston has reached the lowest point of its travel, and again closes this passage when the piston has ascended. At that instant the outlet to the drain, or exhaust, as it may be called, is opened through the three-way cock, and the water which has flowed into the cylinder from below is free to escape.

The chemical from the elevated tank then flows by gravita-

tion into the cylinder from above. To do this it must past through a second three-way cock, which is turned by the tappet simultaneously with the other cock, and so closes the outlet towards the throat and opens that to the cylinder. The chemical, flowing under a moderate pressure, lowers the

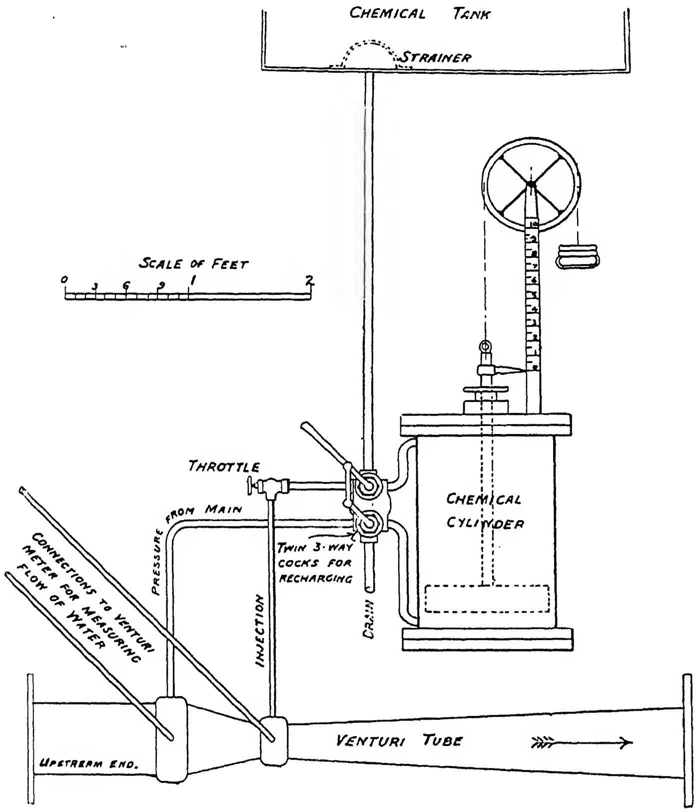


FIG. 32.—DIAGRAM OF MANNOCK AND SIBLEY'S PATENT INJECTOR.

piston, expels the exhaust water, and itself fills the body of the cylinder. As soon as the piston reaches the end of its stroke, the tappet turns the twin cocks, closing the chemical inlet and opening the outlet from the upper part of the cylinder to the throat. It is then that the difference of pressure between the upstream and throat comes into play, with the result that the piston ascends and injects the chemical into the Venturi tube.

The whole mechanism is simply designed, and the working parts are in no danger of getting out of order.

The piston and rod are counterbalanced, so as to make the

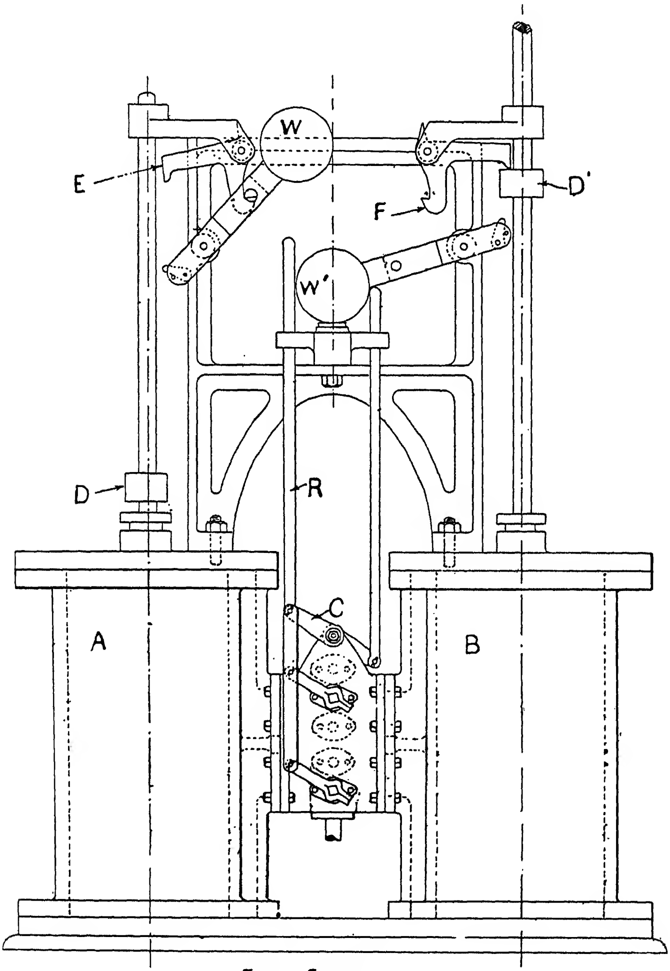


FIG. 33.—MANNOCK AND SIBLEY'S HIGH-PRESSURE CHEMICAL INJECTOR.

movement as easy as possible. The apparatus is self-starting, and the rate at which it injects the chemical always depends on the rate of flow in the main. It is also self-stopping, for

when the flow is interrupted in the main the head from the Venturi tube is nil.

In order that the injection may be continuous there are two cylinders, so that while one piston is on the upstroke the other is descending.

The construction is shown in the accompanying diagram (Fig. 33). C and C′ are the three-way valves to top and bottom of the cylinders A and B, and at the position shown the chemical is being injected from A, and is just commencing to fill B. It will be observed that the chemical always occupies the part of the cylinder above the piston.

On the piston-rods are bosses, D and D′. When D is passing the weight lever W, it comes into contact with the trigger E at the top of the stroke, and tips it. The weight W is thereby released, and in falling quickly reverses the three-way valves.

While the piston in A is ascending, the three-way valve of cylinder B admits chemical above the piston, while the part below the piston is open to exhaust. The chemical causes the piston to descend, and the boss D′ lifts the weight W, which is then held by the catch F.

The cylinder B is now charged with chemical, and as soon as A has emptied itself the boss D lifts the trigger and sets B into action, and from it the chemical is introduced to the main. Meantime cylinder A is recharged from the chemical tank, and as soon as the piston in B reaches the bottom, and that in A the top, of the stroke, the cycle of operations described is repeated.

It has been said that the effective head is that due to the difference of pressure between upstream and throat of the Venturi tube. This difference of pressure is proportional to the square of the velocity of the flow in the tube. It may be shown that the rate of injection under the circumstances varies as the square root of the effective head, *and consequently is directly proportional to the rate of flow.*

For, by Bernouilli's well-known theorem, the quantity of water, Q, travelling through the Venturi tube varies as the square root of the difference of pressure, H—*i.e.*,

$$Q \text{ varies as } \sqrt{H} \quad - \quad - \quad - \quad - \quad (1)$$

Considering now the velocity, V, of the chemical which is forced down the injection tube, we have $V^2 = 2gH$ by the

ordinary physical law, where g represents the acceleration of gravity, and therefore $2g$ is constant.

$$\text{Hence V varies as } \sqrt{H} \quad - \quad - \quad - \quad (2)$$

As both Q and V are proportional to the square root of H by (1) and (2) above, they are directly proportional to each other.

With regard to the cost of the Nixon and Mannock Injector, a single-cylinder apparatus to introduce alumina sulphate into an ordinary mechanical filter treating 150,000 gallons per day is estimated to cost about £35, and a twin cylinder about £65. If corrosive chemicals are to be applied, the cylinders must be protected with vulcanite, and the chemical pipes are made of the same material. This involves an additional expenditure of £5 to £10 only.

The Quality of the Raw Water must be taken into Account.— The regulation of the dose attempted in the above arrangement would serve the purpose desired if the amount of coagulable matter in the raw water were approximately constant. That, however, is far from being the case. Particularly in supplies drawn from moorlands (L.G.B. Report on Lead-Poisoning and Water-Supplies, vol. ii., pp. 10, 11), the amount of acids that requires to be eliminated is much increased at certain times, and under circumstances that may arise at any moment. Therefore the automatic regulation of the coagulant supply is rendered impracticable in such cases.

What is perhaps more troublesome is that the freshets, which bring down large quantities of acid water, are mostly soft rain water with insufficient carbonate to react with the sulphate of alumina. Thus, unless the management is careful and discriminating, the undesirable peaty matters will escape removal.

To add a large excess of coagulant is not an expedient to be recommended, particularly where there are no settling tanks. Part of the chemical is likely to escape the reaction and pass on to the service mains. Cases of this nature have occurred.

It would appear that the attempts to regulate automatically the amount of the dose can claim a partial success only. Accommodation can be made for variation in the flow of the water, not for changes in its quality.

The question of adequate mixing will no doubt be more care fully inquired into, and it may be said at once that it would be an advantage to introduce the coagulant by several inlets placed at intervals round the circumference of the main pipe. This would make for a better distribution.

The smallness of the volume of water in which the coagulant is dissolved is unfavourable to ready intermingling. Thus, it would seem to be better to dilute the saturated fluid with several times its own volume of water.

Analyses of the effluent should be made periodically, not only to test the general efficiency of the filter, but also to make certain that the sulphate of alumina is not passing away to any appreciable extent in solution.

OTHER COAGULANTS.

A cheap substitute for the purer sulphate of alumina is the substance known in trade parlance as "alumino-ferric." This is an impure sulphate of alumina, which contains a little iron. Generally its composition may be put down at 50 per cent. sulphate of alumina and 1 per cent. of sulphate of iron. The other constituents are chiefly combined water and a little insoluble matter.

Alumino-ferric is made from a species of bauxite which is rather highly charged with iron oxide. The presence of iron does no harm beyond reducing the coagulating power which pure sulphate of alumina possesses. For that reason, and also on account of the insoluble impurity, alumino-ferric does not command so high a price as the purer coagulant. The analysis generally indicates a small percentage of free acid in the cheaper substitute, but not sufficient to affect the supply water to any appreciable extent.

The use of dissolved iron salts as a precipitant is referred to at length under the Anderson process. Where, as at Paris, the crude water is adapted for the taking up and subsequent precipitation of the iron compounds, the system works to great advantage (p. 140).

Permanganates as Coagulants.—Valuable at once as a coagulant and a germ-destroyer is permanganate of potash or of soda, which is the active constituent of various disinfectants. Two molecules of the permanganate yield up five atoms

of oxygen, which are ready to act upon organic matters and to destroy bacteria. At the same time insoluble oxide of manganese is produced, and this body acts as a precipitant.

The sterilization of water by permanganate has often been effected on a small scale. The cost is, however, too high for

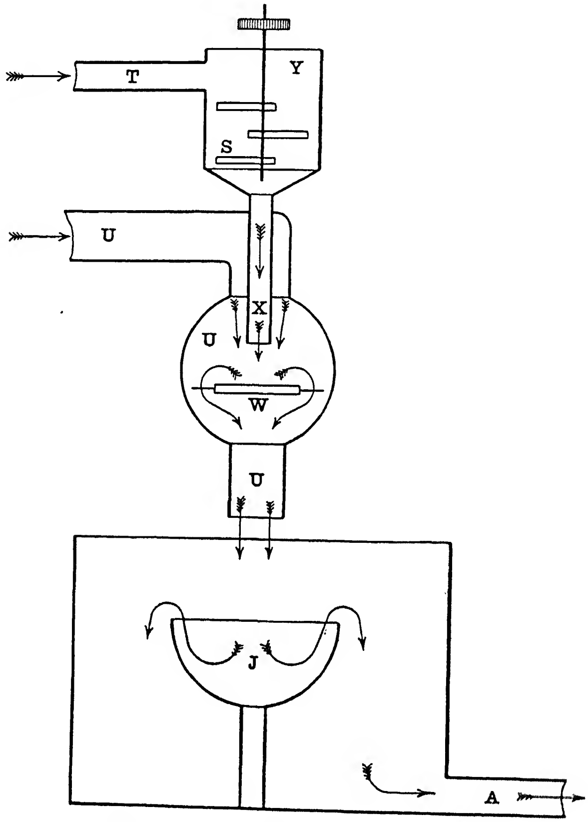


FIG. 34.—AQUA SANA PURIFIER.

T, coagulant inlet; Y, funnel; S, baffle plates; U, raw water inlet; W, baffle plate; J, mixing basin; A, outlet.

large installations, and the precipitate formed is not so effective in the way of removing suspended matter as the oxide of alumina.

Aqua Sana Process.—Somewhat similar to permanganate in its action is phosphate of soda and the acid phosphate of

lime. These, when added to the raw water, unite with salts of lime or magnesia, and disengage a precipitate which is to some extent colloidal and exhibits remarkable powers of carrying down bacteria. This system of purification is known as the "Aqua Sana," and its promoter, M. Calzavara, contends that the cost of coagulant per 1,000 gallons will not exceed one farthing.

The method of mixing the phosphate of lime or soda with the inflowing water well deserves attention. It is illustrated in Fig. 34. The dissolved coagulant enters by the pipe T, and the raw water by way of U, the two conduits being concentric. Mixing takes places at the baffle-plate W, and again at the splash basin J.

The precipitation is encouraged by conducting the water into special chambers, in which retardation of the current and change of direction, with occasional aeration, are brought into play.

CHAPTER VII

MECHANICAL FILTERS

The term "mechanical" has been given to various appliances which have been designed to replace the sand-filter. The natural filtering skin is dispensed with, and an artificial film is employed. The latter is in general viscous and tenacious, and the purification process may go on at a rate many times greater than could be attempted with the ordinary sand-bed. Hence the mechanical filter requires a much smaller area of filtering material, and it is more compact and manageable, while the process of cleaning is greatly simplified. All the operations required for the working can be effected by handling a few levers and valves, so that the charges for labour are low. The filtering materials are not brought into contact with the workmen's clothes. As commonly built of iron plate or of wooden staves, the mechanical filter is durable and the depreciation is trifling.

The usual filtering material is selected sand or crushed quartz, and in some cases a special substance of great purifying power (polarite or oxidium) is used in addition. In this case an artificial film is unnecessary (Candy filter), and the economy in working costs is very notable.

Time required for Filming.—Owing to the high rate of filtration, which may reach 200 inches per hour or more, mechanical filters require frequent cleanings, twice a day being usual. Where coagulants are employed, the film does not form immediately after a fresh run is started, and some little time must be allowed to elapse before the effluent can be considered safe. Probably eight or ten minutes would suffice in most cases, but tests require to be made for each particular installation. In this respect the results tabulated below are

instructive. The effluent from two common types of mechanical filters was sampled and examined bacteriologically at intervals of a minute from the time that the new run was commenced. The improvement in both cases was notably rapid, but incidentally the results show that the *percentage* reduction is not the safest criterion of reliability. Filter No. II., which had to deal with a higher initial content of germs—viz., 249 per cm^3.—shows a better percentage purification than the other, which actually only left half as many bacteria in the filtrate.

TABLE XI.

	No. I. Type of Filter.		No. II. Type of Filter.	
	Number of Bacteria per Cm^3.	Reduction per Cent.	Number of Bacteria per Cm^3.	Reduction per Cent.
Raw water	86	—	249	—
Filtrates (samples taken)—				
After 1 minute ..	56	35	68	72
,, 2 minutes ..	53	38	54	78
,, 3 ,, ..	43	50	28	89
,, 4 ,, ..	62	28	28	89
,, 5 ,, ..	52	39	13	95
,, 6 ,, ..	28	67	12	95
,, 7 ,, ..	22	74	16	93
,, 8 ,, ..	18	78	30	88
,, 9 ,, ..	15	82	15	94
,, 10 ,, ..	7	91	13	95

Experimenting with Lake Müggel water, Dr. Schreiber found that the effluent from the Jewell filter was satisfactory after twenty minutes, and Dr. Bitter at Alexandria showed that the bacterial content is relatively high for ten minutes, and it sinks to a normal figure soon after.

It is thus clear that the first runnings of the cleaned filter are imperfectly purified and ought to be rejected. This does not entail the loss of any large volume of water, as the outflow may be greatly reduced during the interval of suspense. The film does not form with equal facility in different kinds of water, and with very soft qualities lime must be added to bring about the necessary precipitation of the coagulant. Hence the proper management of a mechanical filter demands expert knowledge on the part of the water manager, and at least as careful attention as the sand-filter. Regular tests of

the effluent ought to be carried out. In particular, the influence of varying conditions of the raw water must be noted. Supplies from moorland districts often run soft in rainy weather, and there may be an incomplete precipitation of the chemical added, so that some portion escapes with the effluent. Any contingency of this nature can be provided against if the installation is under intelligent supervision.

Reckoning the average cost of several of the best-known types of mechanical filters, it may be said that the expense of constructing sand-filters would be about double that of installing mechanical filters to deal with an equal quantity. Working expenses in the latter case would be less by 25 per cent., and by 75 per cent. if coagulants are not employed.

Chemical Purification in Mechanical Filters.—During the rapid passage of water through the filtering media of mechanical filters, the chemical content of the water is very considerably affected. There is often a marked decrease in the amount of ammonia, both free and organic, and in the "oxygen consumed." In making a comparison between the raw and the filtered water, it must be borne in mind that a part of the improvement is due to the removal of suspended matters, and that the changes produced are only in part attributable to the betterment of dissolved impurities.

The coagulant applied draws down colloidal bodies, and, further, the particles of sand, with their slimy coating, exercise their adsorptive influence on organic matter in solution.

Referring first to the analyses of waters treated by the Jewell filter after sedimentation, it appears that the organic matter in the Alexandria supply is diminished by 15 per cent. In his tests with an experimental Jewell filter at Lake Müggel, Dr. Schreiber found a reduction of 30 per cent. by the "oxygen consumed" process as the average of many trials. Higher results have been obtained at Little Falls, U.S.A. (p. 174).

Bell filters are in use at Buxton to deal with water after storage, and there the free ammonia decreases from 0·004 per 100,000 to 0·001 part. Albuminoid ammonia declines from 0·020 part per 100,000 to 0·008, and organic matter, as judged by the oxygen consumed, falls 80 per cent.

The stored waters at Morley from the Victoria Reservoir are passed through Mather and Platt filters. These effect a reduction of 36 per cent. in the albuminoid ammonia, and 40 per cent. in the "oxygen consumed." Very similar work is accomplished by these filters at Rothesay and Lanark, which take water from lakes. At Kirkcaldy there is a storage reservoir, and the results are somewhat better even than those obtained at Morley.

As might be expected, the polarite and oxidium used in the Candy filters act powerfully on organic matters in solution. Dr. Thresh has tested the properties of these filtering media, and it is found that albuminoid ammonia is reduced by about 80 per cent. with oxidium, and by 60 to 75 per cent. with polarite. Both media remove the free ammonia almost completely, only traces being left. The total organic content is very much diminished.

THE JEWELL FILTER.

The **Jewell Filter** is the outcome of numerous experiments, made in America, with the view of finding a substitute for the open sand-filters. The muddy waters of many of the rivers cannot be readily freed from sediment by the older system. In the northern States open filters freeze in winter, and their working becomes unsatisfactory. Hence it is most desirable that the sand-beds should be put under cover, and this is scarcely possible with the larger installations. Rapid filters occupy so much less area that they can be roofed over without adding greatly to the capital outlay. In summer the sand-filters are apt to be choked up with too luxuriant a growth of algæ, and not unfrequently these plants import disagreeable smells into the supply. Were the filters roofed in, this trouble would disappear.

Effective Working of this Filter.—The Jewell filter has been subjected to exhaustive tests in America, at Berlin, and at Alexandria, and it has won the approval of its examiners. Dr. Schreiber of Berlin certifies that its efficiency is equal to that of a well-working sand-filter. The Jewell filter was set to work upon the waters of Lake Müggel, which contained a large number of germs per cm^3. The effluent showed very

few. Additional bacteria were added to the raw water to bring up the content to thousands per cm^3., and the filtered liquid was shown to hold less than a hundred—often, indeed, only twenty or thirty—germs in the same volume. At Alexandria, where these filters have been at work for a number of years, the bacteriological results are satisfactory.

The Mahmoudieh Canal supplies the raw water, and it is constantly and openly polluted. The canal leads the Nile water from a point forty-five miles above the city, through a stretch of arable land, and past many Egyptian villages, which add their defilements. Rapid filtration after the application of a coagulant produces from this unpromising source a supply not inferior to that which is distributed to many European cities. Before being finally adopted by the municipality of Alexandria, the Jewell filter was put through a prolonged series of tests by Dr. Bitter, Director of the Egyptian Institute of Hygiene at Cairo (see p. 171). He has expressed himself as fully satisfied with the efficiency of the plant, and on his recommendation the municipality cancelled a previous agreement with a local water company, and determined to treat the whole supply with these rapid filters.

The construction of the Jewell filter will be understood from the annexed diagram (Fig. 35). The inflow water is brought into an annular space, 5 or 6 inches wide, lying between the filtering cylinder proper and an outer cylinder which surrounds the upper third of it, and rises to some height above it. The inflow from the pipe is thus brought over the sand in currents from the periphery, which are directed inwards and upwards, and so do not disturb the filtering skin. The "head" of water varies according to the amount of work that the filter has done since the last cleaning, and as a rule it ranges from 1 foot to 10 feet. These numbers indicate the head at the beginning and the end of a run. The layer of sand or crushed quartz is about 3 feet deep (at the experimental filter in Pittsburg the depth was 4 feet 9 inches), resting upon a thin bed of gravel, which in turn is supported by the branching outlet pipes, which are bedded in concrete. These branches radiate from a main header, and spread over the whole floor of the drum. Their ends are closed, but they are tapped along their length at intervals of 6 inches, and fitted with brass "screens" standing vertically (see p. 172). There is no room for water

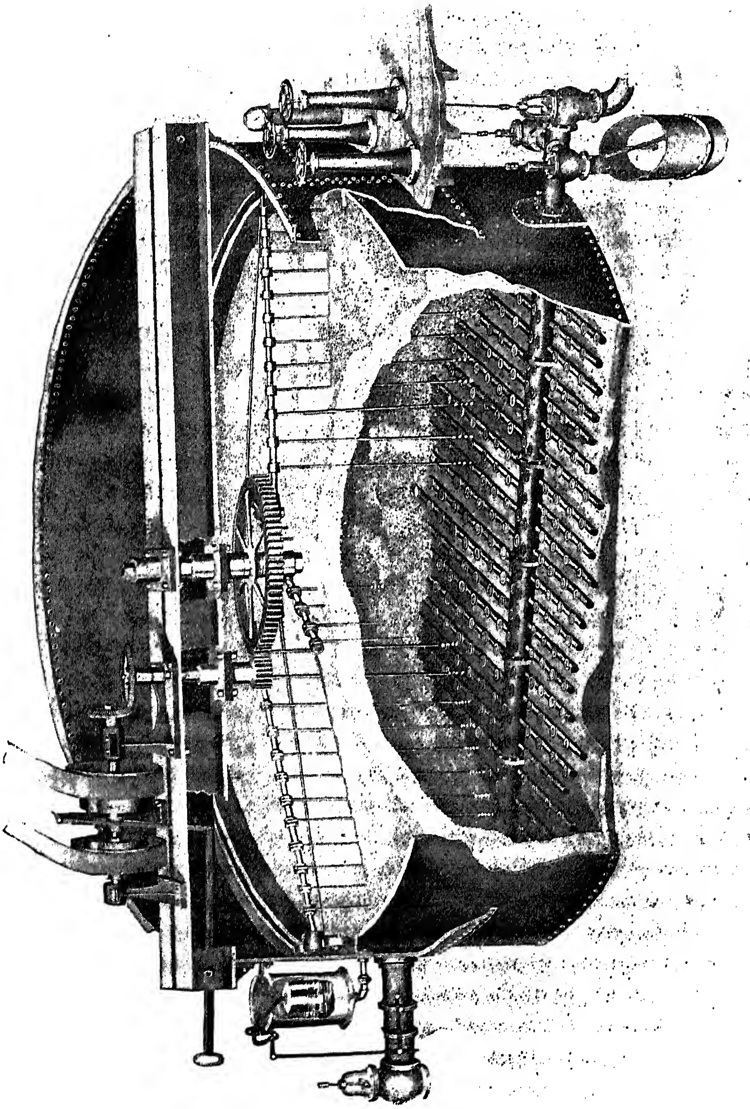


FIG. 35.—THE JEWELL GRAVITY FILTER.

to stagnate under the sand. This is the type of filter installed at Alexandria.

The water leaving by the outlet pipe is passed through a Weston controller (p. 112), which maintains the constancy of the rate of output. A gauge is connected to the controller to indicate the pressure at the time being, and so informs the attendant as to when the filter requires washing.

Cleansing the Filter-Bed.—Washing is performed by first closing the inlet and outlet valves, and opening the washout valve. Filtered water is then admitted, under sufficient pressure from below, and this percolates upwards through the sand, which is meantime vigorously stirred by rods depending from four radial arms, which revolve about a central shaft. Motive power for this shaft is obtained from a small engine, or from a motor or a turbine, according to opportunity. Only four or five minutes are occupied in cleaning, and the wash water is reckoned at 2½ to 5 per cent. of the quantity that filters during the run between two washings.

Method of applying the Coagulant.—The efficiency of this filter depends very largely upon the coagulant. Sulphate of alumina is dissolved in the mixing tanks so as to form a standard solution, and from thence it is conveyed to a regulating chamber, with ball-cock valve for the purpose of keeping the level constant. Connected to this are several special regulating taps which discharge into funnels placed to receive the coagulant liquid. These are connected to pipes through which the liquid flows by gravity into the main carrying the unfiltered water. The rate of flow through each filter being constant, one or more of these taps may be brought into play as required, and as each can be adjusted to constantly pass any desired volume, it is in this way possible to graduate the dose of coagulant.

Sedimentation.—This main in most of the Jewell installations goes direct to a settling tank, in which the coagulant is left to accomplish the chief part of its work. The time allowed for precipitation depends on the state of the raw water, and ranges from one to six hours. At Alexandria the maximum period is necessary, owing to the fineness of the silt and the high percentage of organic matter.

While the greater part of the precipitation effected by the

alumina is completed in the sedimentation basins, there is yet left sufficient coagulant to form a skin on the surface of the sand. In about fifteen minutes after cleaning, the filtrate may be once more turned into the service mains ; such, at any rate, is the experience of the makers of this filter. The addition of a little extra alumina at the beginning of a run is recommended at certain stations, and this is a simple expedient for quickening the growth of the filtering skin.

Particulars regarding the capital outlay, maintenance, loss of time, and waste of water in cleansing will be found in the tabulated statement on p. 384.

The capital cost of the whole purification works at Alexandria, with eight million gallons of water under treatment daily, was under £80,000. But this sum included not only the filters, but also the following : Two covered clear-water reservoirs, two sets of pumps, wash-water tank, settling tank, two new boilers, some new buildings, and many alterations of existing machinery, together with deep excavations in laying the foundations of the new apparatus. There were at first eighteen filters, each 17 feet in diameter. One attendant was put in charge of the washing of all these. The rate of filtration is about 80,000,000 gallons per acre per day—forty times as great as is usual in slow sand-filters.

The following is an extract from Dr. Bitter's report, quoted in the *Zeitschrift für Hygiene und Infectionskrankheiten*, vol. lix., 1908 :

" In view of the exceedingly favourable results of our tests, we did not hesitate to recommend the Jewell system of filtration for the water-supply of Alexandria, and the municipality decided to erect a plant capable of dealing with 36,000 cubic metres (8,000,000 gallons) daily capacity. This was completed in two years, and, with subsequent additions, it now consists of twenty filters of 17 feet diameter.

" At present, with the normal rate of filtration of 166 inches per hour, the day's yield of filtered water amounts to 9,000,000 gallons. The installation has been working for two and a half years to our fullest satisfaction. It is under our constant supervision and control, bacteriological tests having been made during the first six months every day for each filter separately.

As the results were exceedingly uniform and excellent, tests are now made in the following way :

" 1. Daily turbidity tests of raw water, effluent from the sedimentation basins, and the service water.

" 2. Daily bacteriological tests of the water drawn from the city pipes.

" 3. Twice a week bacteriological tests are made of the effluent from each filter separately.

" The analyses show that the number of bacteria in the filtrate varies from 9 to 27 per cm^3. The content of the raw water is subject to wide variations, and may range from 700 to 5,000 per cm^3., taking averages of the maxima and minima.

" The largest number counted in the crude water was over 19,000 per cm^3., and the maximum discovered in the filtered water was only 61 in the same volume."

THE JEWELL PRESSURE FILTER.

The term " pressure filter " is a misnomer to a certain extent, seeing that the effective head never exceeds a few pounds per square inch. It is simply endangering the continuity of the film to increase the working head beyond 10 feet of water, and this difference of pressure is not outside the limit of a gravity filter. Hence the possibilities of rapid filtration are equally good in the one type of filter as in the other.

The Jewell Filter Company do not recommend the use of pressure filters for treating municipal supplies, but it is often an advantage to use them for commercial installations, particularly where they save the cost of double pumping. One pattern of a Jewell pressure filter is illustrated on p. 173, Fig. 36.

Gravity filters, being open above, are more easily kept under observation. They do not require to be so strongly built as pressure filters, which may have occasionally to withstand a considerable strain, and in consequence larger units may be constructed without incurring great expense. They operate well when the coagulant has been previously applied in a sedimentation basin. The working head, being the difference between the outside and inside levels, can be adjusted automatically, and there is no risk of undue pressure. One obvious disadvantage is that the gravity filter cannot be introduced directly on the mains, and consequently the whole of the available head between the source and the filtering-station is lost. This may not be a very serious drawback in

view of the modern opinion that the filter's effluent should not be connected directly to the service mains.

Perforated Nozzles of Special Form under the Sand-Bed.—There is an ingenious arrangement in the Jewell filters for preventing the upward displacement of the sand-bed when the

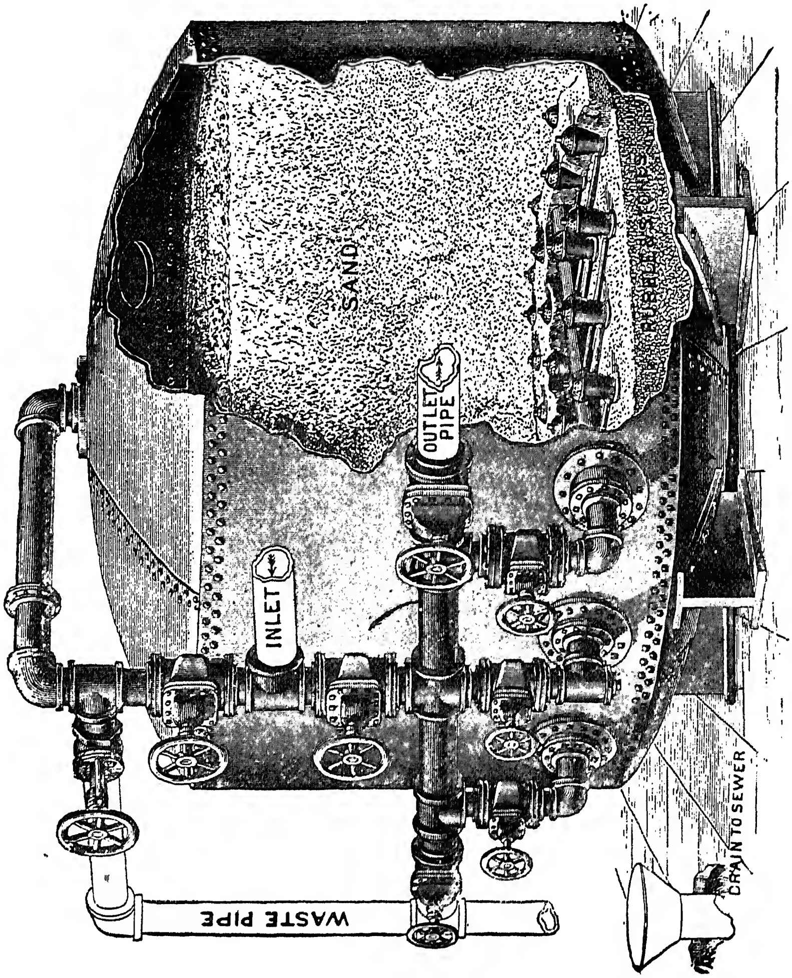


FIG. 36.—THE JEWELL PRESSURE FILTER.

wash water is forced in from below. In general, with chamber filters, the water is projected from a series of nozzles directed upwards. The force of the incoming current lifts the sand and disarranges the gradation, if such exists. In the Jewell filter the nozzles are replaced by flat roses or screens, directed

horizontally. Each rose is in the form of a hollow disc, perforated on both sides. It is connected by its edge with a branch feed-pipe, and stands vertically, like a carriage wheel. The discs face in different directions, and distribute the wash water horizontally without in any way disturbing the gradation of the layers of the sand-bed.

One of the most important installations of this type of filter has been set up at Little Falls, New Jersey, U.S.A., for the purification of the supply of Paterson, Montclair, Passaic, and other populous centres. The daily capacity is 32,000,000 U.S. gallons.* There are thirty-two filters, all built of reinforced concrete, rectangular in shape, and with a surface area per unit of 360 square feet. Each having a daily capacity of 1,000,000 U.S. gallons, it is seen that the rate of filtration is rapid, amounting to 185 inches per hour of downward flow.

The intake is a 66-inch pipe, delivering water to a concrete cylinder which receives also the coagulant. The sulphate of alumina is first dissolved to a saturated solution in tanks with stirrers. This concentrated fluid is diluted in a second set of tanks with one hundred times its volume of water, and from these it is pumped to the receptacles situated over the control valves. These are regulated by piston floats, and the head is maintained constant by the simple device of keeping the receptacles full. Any overflow returns to the diluting tanks.

The orifice from which the coagulant issues is rectangular in section, and any desired aperture is arranged for by a slide controlled by the floats. The valve spindle is adjustable by a fine screw, and one end registers on a scale the width of the opening at any time. The coagulant is caught in a funnel and carried to the intake outlet. With the raw water it enters the coagulating basin, which has a capacity of about 80 minutes' flow. The outlet pipe to the filters dips 3 feet under the surface of the water in the coagulating basin, which requires to be cleaned from time to time. Sludge pumps are installed for this operation.

V **Method of Economizing Working Expenses.**—The discharge from the filters is regulated by Weston controllers (p. 112). The working of the filters is simplified in an ingenious manner by concentrating all the valve levers on an operating table. The valves are primarily moved by hydraulic cylinders

* The U.S. gallon is five-sixths of the British gallon.

supplied from a special high-pressure line. The six levers of any one filter are ranged on a table, and behind them are indicators showing the position of the valve. On the same table are tubes from which samples of the raw and filtered water may be taken. Lastly, there are electric push-buttons whereby the motors operating the wash water and the blowing mechanism for cleansing are brought into action. Just behind the table is a "loss of head" gauge.

It will be readily understood that the working expenses are here brought down to a minimum, as one attendant is able to manipulate a dozen filters.

Washing is performed by blowing air into the bed from below, and scrubbing with water under pressure. The same system of piping is used for both air and water. The filters are washed twice a day, and the wash water amounts to 4 per cent.

Judged by results, the filtration is good. The bacteria are reduced from several thousands per cm^3. to 100 or less. There is very little colour left, and practically no turbidity. Albuminoid nitrogen falls from 0·012 per 100,000 to 0·007 (40 per cent.), and oxygen consumed from 0·6 to 0·15 (75 per cent.). By varying the rate of filtration from +47 per cent. above normal to −30 per cent. below, it is found that the quality of the effluent is not affected, provided the water is first subjected to thorough treatment with the coagulant.

The Jewell Export Filter Company has set up plant at 220 centres in the United States, which deal with 450,000,000 gallons per day. In other countries Jewell filters are in operation at more than fifty localities, and purify 100,000,000 gallons daily for public supply.

THE BELL FILTER.

While the principle of the Bell filter is identical with that of the Jewell, the construction and method of operation differ in several particulars. The American filter is intended to receive water from a sedimentation basin, and the makers do not intend that it should be connected directly with the mains. The Bell filter is frequently placed to receive the raw water direct from the pipes, and so may accept water under very considerable pressures. The latter range from 30 to 300 pounds per square inch in various localities. The effective

pressure is determined by the difference of pressure at inflow and outflow, and this is so regulated that a maximum of 10 to 12 pounds per square inch is not exceeded (Fig. 37).

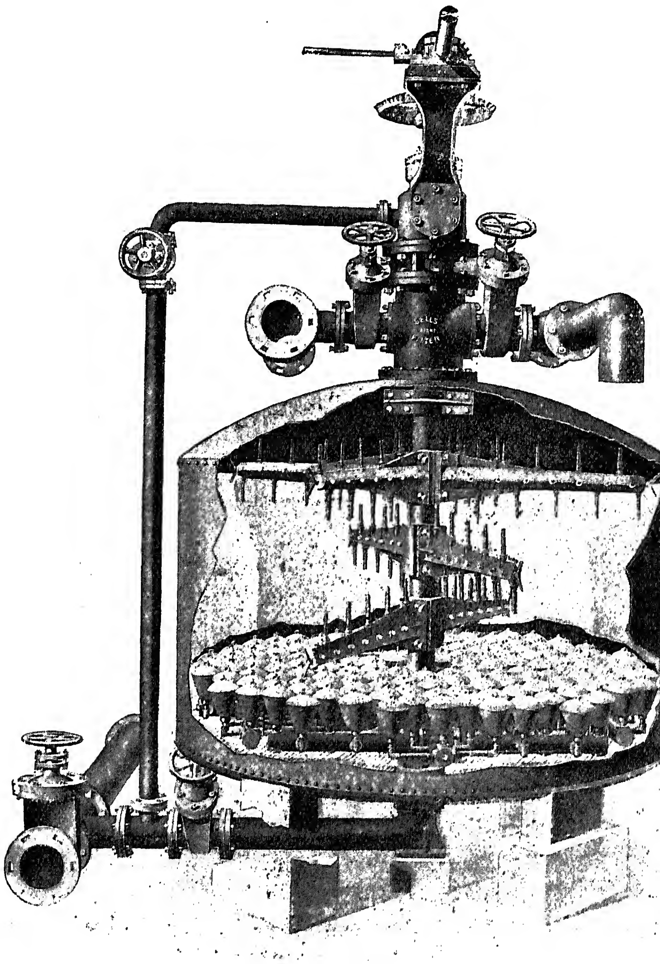


FIG. 37.—THE BELL PRESSURE FILTER.

The introduction and regulation of the coagulant now becomes a matter of some difficulty. The alumina or other chemical is dissolved in a mixing tank, and the saturated solution is pumped into the main some little distance before

it reaches the filter. The delivery of the pump is brought into relation with the rate of flow in the main by the use of a turbine drive, as illustrated in Fig. 29. The solution is preferably injected into the rising branch of the inflow pipe, and it may be divided so as to make its entry at several points around the circumference. It is desirable that as much mixing as possible should be accomplished before the water arrives at the dome of the filter. The turbine itself helps to scatter the coagulant.

This apparatus adjusts the dose to the quantity of raw water passing, and, by altering the length of the crank-arm at the end of the turbine shaft, the stroke of the pump can be made longer or shorter, so as to make an adjustment for the quality of the water possible. Trials made with this arrangement at Strathaven (Lanark) have shown that good results are obtained —so far, at least, as concerns the removal of peaty matters, and the complete exclusion of the alumina from the filtrate.

Being a "pressure" filter, the Bell cylinder is closed above. The incoming water is distributed over the top of the filtering medium, which here consists of pulverized quartz.

Washing is effected by bringing a reversed current of water to bear on the contents of the filtering drum. This is forced upwards through the perforated strainers (Fig. 37). In addition, jets of wash water issue from the revolving rakes which stir up the quartz grains. These are hollow tubes with numerous perforations, and they are fed from the central shaft. The wash water is usually obtained from a second filter, which is linked up in such a way that the effluent may be diverted from the service pipe and directed into the base and hollow shaft of its neighbour. To this procedure there is the objection that the diversion of the flow from the operating cylinder alters the internal pressure, and endangers the continuity of the filtering skin. Another change of pressure occurs when the effluent is again turned back to join the service supply. These risks might be avoided by the provision of an elevated tank for wash water, as is common with Jewell plants.

The proprietors of this filter claim it as an advantage that it can be interposed upon the mains without a clear-water reservoir in sequence. The wisdom of this plan has been already questioned. They also assert that the increased head which is brought to act on the crushed quartz tends to con-

solidate the particles and improve the efficiency. Against this it may be argued that the effective head is least when it is most wanted to bring about compression—namely, at the beginning of a run—and that, after the film has been deposited,

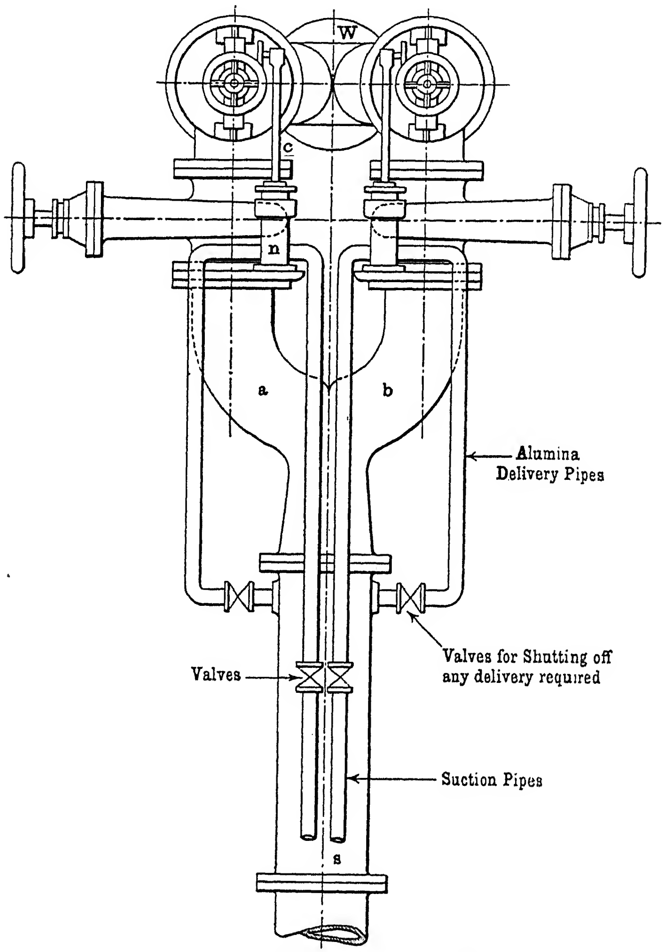


FIG. 38.—BELL'S COAGULANT AND CHEMICAL FEED.

compacting of the granules is more a hindrance than otherwise. It seems doubtful whether the quartz crystals are brought appreciably closer by an extra weight of a few pounds per square inch.

Purification effected by this Filter.—The efficiency of the Bell filter is not behind that of other mechanical appliances that depend chiefly on precipitation by coagulants. Bell filters are installed at Gloucester, and the County Analyst finds no pathogenic germs in the supply water, though these do occur in the reservoirs. The reliability of these filters has obtained for them the most favourable consideration of the Edinburgh Council, and a large number have been set up there to prepare the water for the consumers' use. It was noted by Dr. Hunter Stewart, of Edinburgh University, that *B. coli* did not pass through the Bell filter. Other analysts have given satisfactory reports. Facts relating to the original cost of this apparatus and to the expense of working and other details are tabulated on p. 356.

The Bell filter is installed at over thirty public stations, with an output of 30,000,000 gallons per day. The results at some of the stations are worthy of notice, as showing the high degree of purification attained. Dr. P. Frankland, in his analysis of the supply of Banbury, which comes from the River Cherwell, found that the reduction of bacteria was close upon 99 per cent. No *B. coli* were found in 100 cm^3. The raw water contains some thousands of germs per cm^3., including sewage types.

The water from the reservoirs at Stanley Moor, Buxton, Derbyshire, is purified by Bell's filters, and a number of analysts of standing have examined the raw and treated waters, and have certified a reduction of 98 to 99 per cent. in the number of germs. The stored water is of comparatively good quality, but as many as 500 germs per cm^3. are present. The filtrate contains no *B. coli,* and only twenty of harmless types on the average.

The town of Shrewsbury draws water from the Severn, which is polluted to some extent. By treatment with Bell's filters, a content of 800 bacteria per cm^3. is brought down to six. Dr. Reynolds, Medical Officer of Health, gives, as the result of a test analysis, that, out of 166 bacteria per cm^3. which could grow on a special medium at blood-heat, only two per cm^3. were left in the service water, while *B. coli* was not detected in less than 500 cm^3.

Bell's Apparatus for introducing Coagulant into Mechanical Filters.—The method of applying a turbine drive to inject

coagulants into the supply pipe to mechanical filters is well illustrated in the end elevation of the apparatus used for the Bell filters at Edinburgh (Fig. 38). The main conduit, *s*, to any particular filter is branched near the middle of the rise, and the twin pipes, *a*, *b*, are deflected backwards, so as to lie

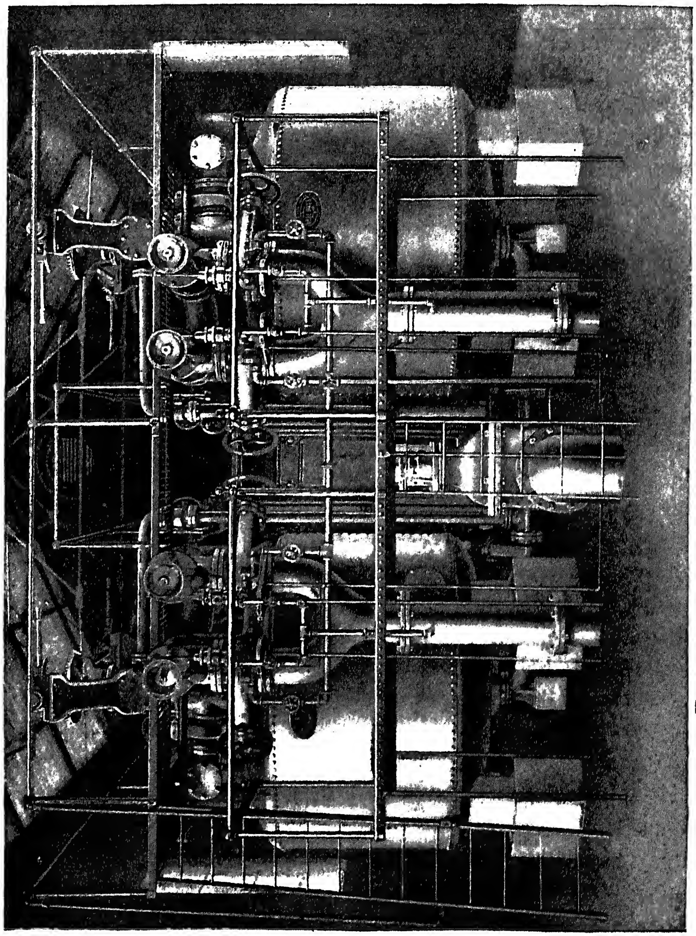


FIG. 39.—BELL'S COAGULANT FEED AND FILTER.

horizontally. At a distance of 4 feet they once more unite in the common pipe, *W*. In each of the horizontal branches is placed a turbine, which drives a pinion by worm-gearing. The connecting-rod, C, puts this into play with the gun-metal ram-pump, *n*, which draws the coagulant from the mixing

tanks and impels it into the delivery tubes. There are valves for shutting off the supply to any of the turbines, thus providing for variation of the dose. The twin turbines would also permit of the application of two different chemicals wherever that form of treatment was desirable. A general view of the filters and coagulant feed is given in Fig. 39.

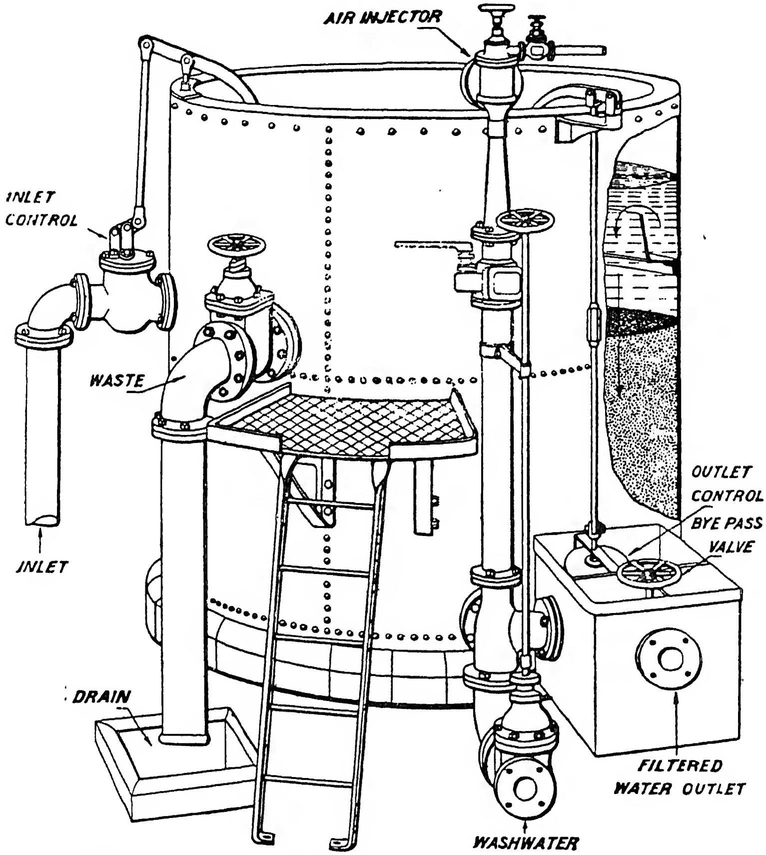


FIG. 40.—PATERSON GRAVITY FILTER, CLEANSED BY AGITATION WITH COMPRESSED AIR, AND FITTED WITH AUTOMATIC OUTLET CONTROLLER.

PATERSON'S GRAVITY FILTER.

Paterson's gravity filter and pressure filter differ in no essential detail from the mechanical devices already described, but the cleansing is carried out by means of compressed air. An air-compressor is required for the purpose, and, in order to distribute the blast over the whole bed, the current

is made to ascend from below through a very large number of conical nozzles covered by perforated screens of phosphor bronze. It is claimed that the bed of crushed quartz is thoroughly broken up, and the dirt can be detached without

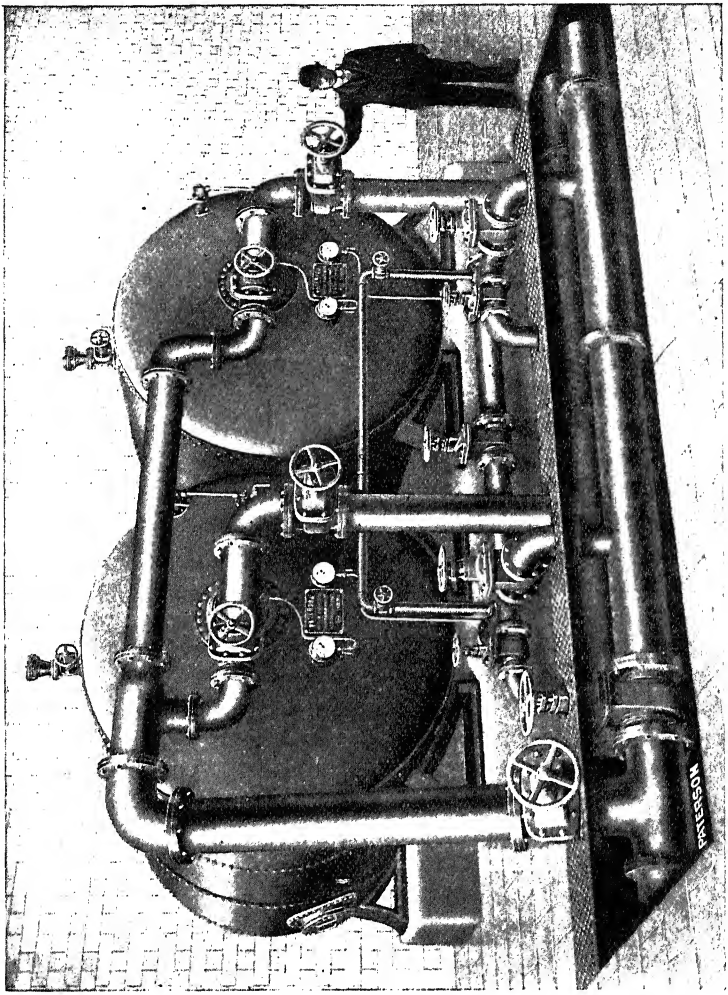


FIG. 41.—PATERSON HORIZONTAL PRESSURE FILTERS.

any great expenditure of wash water. First, the air is made to agitate the bed for half a minute, and then the wash water is turned on. An inspection chamber with draw-off tap enables the attendant to see how the operation is proceeding. The output of the filter is regulated by an automatic controller, which insures the constancy of the flow (Fig. 40).

PATERSON'S PRESSURE FILTER.

In this filter (Fig. 41) the apparatus for stirring up the sand is entirely dispensed with, and the cleansing is effected by a current of compressed air which is forced into the bed from below. It is claimed for this system that a more uniform agitation of the sand is obtained, for with revolving rakes that portion of the sand which lies close to the axis of the drum is hardly broken up at all, while parts near the periphery are excessively agitated.

There is a considerable saving of wash water, for it is not necessary to apply a back-current of water until the compressed air has done its work in loosening the slime and dirt.

It has been objected to this mode of cleaning the filter that the air seeks an outlet by the easiest route, and much of it may escape through fissures and weak places, so that the firmer and more compacted portions of sand are not broken up at all. But in the Paterson filter the air is introduced through so large a number of minute openings that each section of the sand-bed is brought directly under the influence of the compressed air, and a uniform and complete agitation of the sand is assured. The filter is thoroughly aerated at the same time. Paterson filters are in use at more than a hundred important stations, and deal with nearly 10,000,000 gallons daily.

MATHER AND PLATT'S PRESSURE FILTER.

It is believed in some quarters that a thin sheet of water can slip down the sides of a mechanical filter, and in a measure escape treatment. To meet such a contingency, the Mather and Platt filter is contracted from above downwards in the manner of the frustum of a cone. But drums with parallel sides are also constructed by the firm (Fig. 42).

The filter casing has a false bottom fitted with a number of specially-designed nozzles for distributing the wash water entering from below. They also permit the escape of the filtered supply from the sand-bed. These nozzles are screwed in from below to facilitate replacement in case need should arise.

Method of Sand-Washing.—A very effective method of sand-washing has been adopted by the makers of the filter. As will be seen from the diagram, there is a central tube of large size

situated in the middle of the filtering material. Suspended in the tube is a steel shaft on which are fixed propeller-like

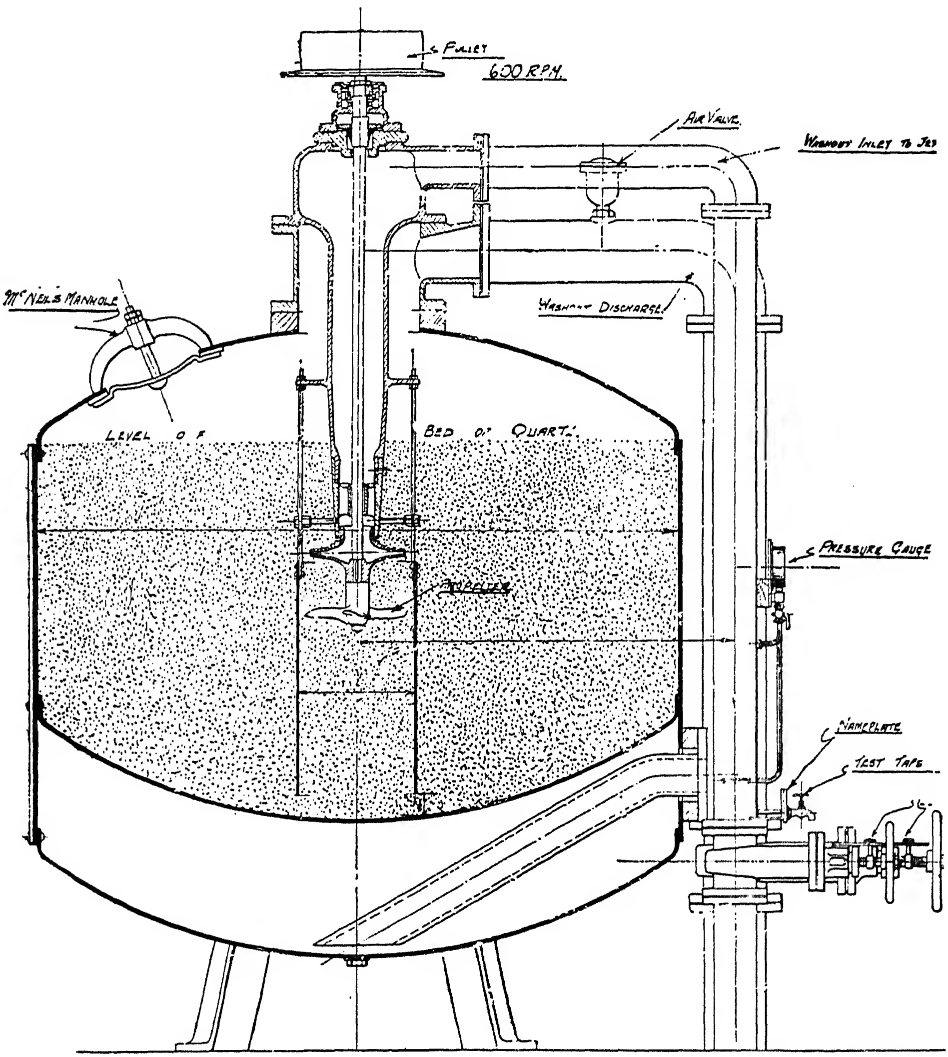


FIG. 42.—MATHER AND PLATT'S PRESSURE FILTER.

blades. On the shaft are too jets connected to the filtrate main for the purpose of discharging water and washing the sand. When the shaft is revolved, the filtering material is

drawn up the vertical tube, and passes over the upper extremity of the vertical tube, which may be expanded into a bell mouth.

The shaft which operates the propeller is hollow, and it receives the wash water from the inlet above, and distributes it among the ascending sand through sprayers attached to its walls. During the washing the current is reversed through the false bottom, so that there is an entry of wash water from above and below at the same time. As the filtering material is thrown out from the vertical tube, it settles down over the surface, while the foreign substances are carried away by the wash water to the outlet, which is near the top of the filter.

The raw water is brought into the upper third of the drum, and distributed over the surface by means of a circular perforated conduit lying close to the periphery. The filter-bed consists of crushed quartz of average grade. The coagulants used are sulphate of alumina and a milk of whiting and water for soft waters, and the former alone is used when the water holds sufficient lime to react with the coagulant.

The machinery for introducing the coagulants consists of a turbine driven by the flow in the main pipe, which actuates both a stirrer in the whiting tank and the pumps for delivering the chemicals. The dose is thus proportioned to the flow The continual stirring keeps the milky fluid of uniform strength. The pumps draw from the chemical tanks which have been charged with the day's supply, and convey the liquids to the inlet pipe. A regulated supply of water is fed into the tanks, and while the whiting is sufficiently screened from the suction inlet by baffle-plates, the sulphate of alumina is thrown on perforated plates near the surface of the liquid. It is usual to have two alumina tanks, so that the crystals may have one day to dissolve and saturate the solution before it is drawn off by the pumps.

MATHER AND PLATT'S GRAVITY FILTER.

Mather and Platt's gravity filter is similar in build to the other, but the cylinder is open at the top, and it rises to a height of 15 feet, so as to provide for considerable head of water. The pipe which carries in the raw water is brought down nearly to the surface of the crushed quartz, but the jets are so directed that the currents produced do not disturb the bed. These

gravity filters have been favourably considered by municipalities, and they are in use at Kirkcaldy, Rothesay, Morley, and at the Ashton-under-Lyne, Stalybridge, and Dukinfield Waterworks, where thirty-three filters were recently installed.

As regards efficiency, Mather and Platt's filters rank among the best of their kind. Nearly 30,000,000 gallons of water are daily treated by them for household use. The analyses of the Rothesay supply by Mr. Bevan, Analyst to the County of Middlesex, show that the bacteria are reduced from 300 per cm^3. to 10 in the same volume. The Kirkcaldy plant has given complete satisfaction for a period of years, as has that at Hereford, dealing with River Wye water, which is often very turbid and otherwise impure.

THE TURN-OVER FILTER (PATENT).

In the turn-over filter here illustrated (Fig. 43), the crushed quartz rests on the perforated bottom J, beneath which is the pipe N, with ports, *e, e, e,* to admit filtered water and carry it to the outlet through the conduit N. Raw water enters the cylinder from the pipe E′ by way of the port H, and flows over the quartz bed. From the figure it is observed that the cranked pipe E′ is blanked off at the left-hand side, so that the raw water cannot go beyond the bend there. On the underside of this pipe are three ports, *d,* projecting down for some distance. These are closed while the filter is in service, and only come into action during the cleansing of the bed. The lever G is used to move all the valves on the cranked pipe. By a link and bell-crank mechanism, valve *b,* on the outlet H, is closed when the valves, *a,* on the three ports, *d,* are opened, and *vice versa.*

The operation of cleaning is as follows: The raw water is shut off, and a reverse current is passed from the left-hand side of the cylinder through the pipe N, the passage I, and the ports *e, e, e,* into the space beneath the screen on which the quartz rests, whence it rises through the quartz. While this is going on, the cylinder is rotated by worm-gearing and pinion, so that the bed of quartz is turned over and over as the wash water mingles with it. Very soon the water rises to the level of the port H, and begins to overflow to the waste-pipe. As soon as this happens, the lever G is used to close H and open the three valves on the under-side. These at once siphon off

the dirty water, and clear it away before the sediment which it carries has time to settle. The process is now repeated, more water being admitted and again siphoned away until the wash-

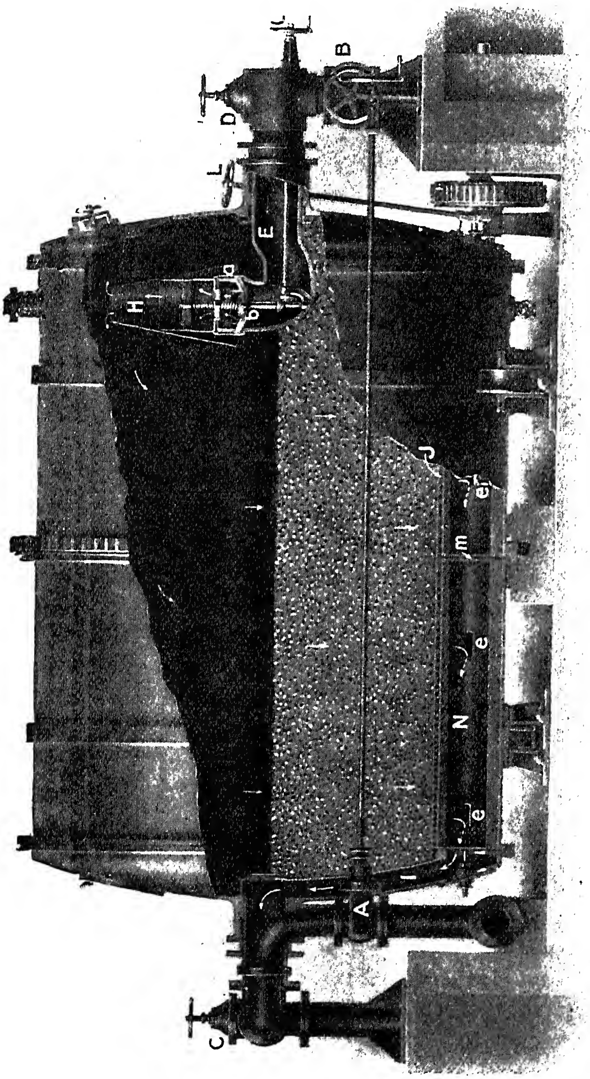


FIG. 43.—THE TURN-OVER FILTER (PATENT).

E′, raw water; H, inlet; *b*, valve; G, valve lever; N, filtered water; I, outlet; *e*, port from sand bed; *d*, wash-out port; K, turn-over cylinder.

ing is complete. The crank-pipe E′ does not revolve with the cylinder, and the port H is always directed upwards. The bed is divided by transverse partitions into three compartments, and for this reason there are three ports below and three

valves above. With this arrangement it is possible to wash the compartments separately, and concentrate the whole weight of the wash water on one at a time. For the ports are also provided with valves, which may be closed at will separately by a lever outside. In general, two outlet valves are in position at the left-hand side, so that, if necessary, the first runnings after cleaning may be led to waste. The cylinder, it will be noticed, is supported by rollers so as to relieve the strain on the trunnions. Motive power for revolving the filter is obtained from a motor or otherwise, as convenient. The cylinder here shown is 12 feet long and 8 feet in diameter, but smaller units are also made which may be easily turned by hand. The friction of the quartz on the metallic walls of the cylinder as it revolves keeps the interior bright and clean. The filter is constructed with connections for introducing coagulants where these may be required.

THE CANDY FILTER.

It has long been recognized among chemists that oxidation must play an important rôle in the purification of water containing organic matter. Naturally, it was concluded that porous substances like coal and charcoal, which occluded air in their pores, would be very suitable media for filtration. Nor is this conception at fault. In percolating through these materials, the albuminoids, nitrites, and colloids, are powerfully acted on, and germs are retained or exterminated. There is but one difficulty with charcoal as a filtering medium, and that is the unfortunate tendency to become clogged when used in submerged filters, and so saturated with decomposing matters that cleansing becomes wellnigh hopeless. Hence it is hardly looked on as a practicable purifier in this country—at least, for continuous public supplies.

Oxidium and Polarite.—In Britain, substances akin to charcoal in their power of absorbing air have been patented, and applied with success to the purification of water. These materials are polarite and oxidium, both of which are the invention of Mr. Candy. They may be described as porous compounds of iron oxide, silica, lime, magnesia, etc. The per-

centage composition of polarite, according to Sir Henry Roscoe, is as follows :

	Per Cent.
Magnetic oxide of iron	53·85
Silica	25·50
Lime	2·01
Alumina	5·68
Magnesia	7·55
Carbonaceous matters and moisture	5·41
	100·00

Owing to its porous and vesiculated nature, and also to the special chemical affinities of its components, polarite is able to occlude a large volume of oxygen. When water holding organic substances in solution or suspension is made to filter through a bed of this compound, a process of wet combustion goes on by aid of the occluded oxygen, which in this condition seems to be more active than oxygen in its free state. In several tests made by Dr. Thresh, it appeared that albuminoid ammonia had been reduced by 80 to 85 per cent., and the ordinary ammonia was also diminished.

Polarite oxidizes any iron dissolved in water, and causes its precipitation. At Tunbridge Wells polarite filters are employed to remove iron from the town's supply, and they also destroy the small quantity of sulphuretted hydrogen which gives the deep well water a disagreeable odour. At Harrogate, Torquay, and elsewhere, Candy filters deal with waters from moorland gathering grounds which require to be clarified and decolourized.

The Registrar-General called attention to the fact that in the year 1902 the two large towns having the lowest death-rate from enteric fever were Hastings and Reading. Both these places make use of water which has been filtered by the Candy system. In the case of Hastings, the source of the public supply is underground water, which probably runs little risk of pollution ; but the Reading supply is drawn from the River Kennet, which must at times be polluted.

The principal service which the polarite filters at Hastings perform is to remove iron, both in solution and in suspension. This service is well performed, for the water authorities have enlarged their installation of polarite filters. The raw water is described as "very highly ferruginous," and open sand-filtration is troublesome and expensive, owing to the surface

of the sand becoming quickly coated with precipitated oxide, which to a great extent sealed the pores and necessitated constant skimming and paring.

At Newport (Mon.) there were at first six Candy filters installed. That number has been greatly increased, as the Corporation have again and again repeated orders, and in 1909 they added several Candy filters. The chief impurity consists of peaty and discolouring matters, which are picked up in the gathering ground of about three square miles, of which one-half is cultivated and the rest is woodland. All colour is removed by the filtration.

In his report to the South Molton (Wales) Town Council on his visit to the Cardiff and Newport Waterworks in 1908, the Borough Surveyor stated that at both stations the water was collected from upland peaty grounds, and was of a soft nature and discoloured with peat. The filtrate was clear, and without trace of any peaty matter.

Renewal of the Oxygen occluded in the Filtering Medium.— Special means are taken to enable the oxidium or polarite to recover a fresh supply of oxygen when its own store is nearing depletion. The filtering layers are first cleansed by a reverse current of water. No rakes or stirrers are brought into play, for it is found that these are unnecessary. Washing may take place twice a day, or only once in two or three days, according to the state of the crude supply. After completing that operation, the filter is drained out by opening the outlet valve, and air is permitted to enter. Water under the head available is now let into the filter from below so as to compress the imprisoned volume of air as much as possible, thus promoting its absorption by the oxidium or polarite, and also increasing its solubility in the water with which it is in contact. A considerable amount of air is forced into the dome of the cylinder, and there it gradually dissolves in the inflowing water, after the ordinary course of filtration has been resumed. This air so dissolved under pressure aids in renewing the store of oxygen occluded by the filtering substance. When it appears from the gauge attached to the filter that the volume of air imprisoned in the dome is running low, the inflow is stopped, an air-valve is opened and the filter is emptied, and a fresh quantity of air is brought in and once more compressed.

The time required for washing the filters at Monmouth runs to about fifteen minutes, and the recharging with compressed air to seven or eight minutes at most. The filtered water can be led to the service reservoir almost immediately after re-starting. This is a manifest advantage which the Candy filter possesses over other mechanical appliances, for even with coagulants some little time must be allowed for the filtering skin to spread over the surface of the sand.

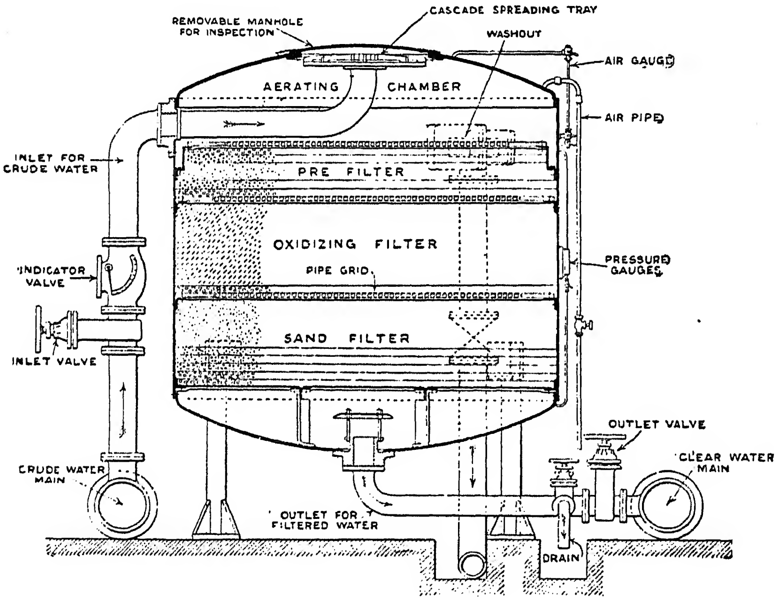


FIG. 44.—SECTION OF THE CANDY OXIDISING FILTER.

A section of the Candy filter of the most recent type is shown at Fig. 44. The filtering material is here distributed in layers graded from coarse above to finer below. The polarite occupies the middle of the cylinder, so that before the water percolates into that layer it has parted with most of the suspended impurities, leaving the polarite to deal with oxidizable matters. This arrangement also reduces the risk of clogging in the most active portion of the filter. Below the polarite is a finishing layer of fine grit to entrap the oxide of iron that may have separated, or any other matter in suspension. Transverse

L_1, as the water begins to filter downwards again. A single air-compressor may serve for a battery of these filters. In the outlet pipe, B, is a regulator, E, which serves to maintain a uniform flow, and also indicates when cleaning is necessary. The device has been applied to open sand-filters constructed on the same pattern as Reisert's. If there be not a sufficient head of water to compress the air, mechanical power must be used in all cases.

The filter has been introduced at Frankfort, Königsberg, Tilsit, and other stations on the Continent.

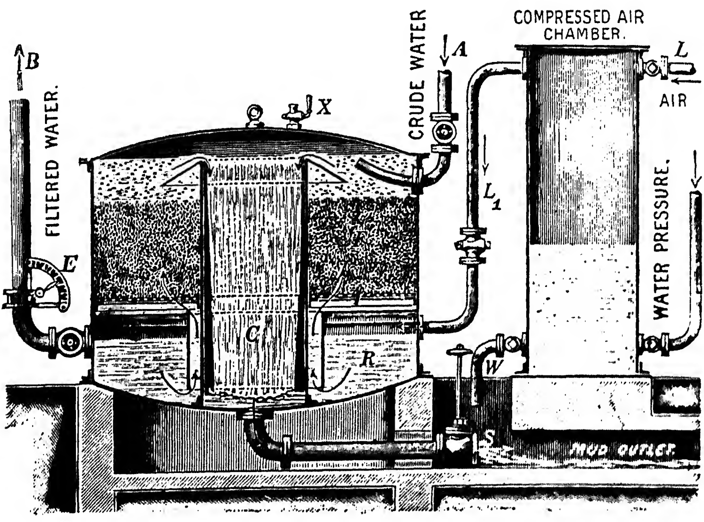


FIG. 45.—REISERT'S PRESSURE FILTER.

A, water inlet; L, air inlet to compressor; W, outlet to water in compressor; F, filtering material.

COKE FILTERS.

The great value of coke as a purifying agent has been to some extent discounted owing to the fact that, in submerged filters as well as in house filters, it has been found to clog and take on a coating of slime which puts an end to its usefulness. Mr. W. C. Wedekind has shown (Proc. Mech. Engin., Lond., January, 1909) that it is capable of working efficiently for many months, and of effecting a satisfactory purification of river water. The most important condition is that the coke must be freely exposed to the action of the air, in order that it

may continually be refreshed with new charges of oxygen to support the activity of the bacteria which gather on the surface. These bacteria feed on organic impurities, and one of the features of a coke filter is the large reduction of putrescible matters which it is able to bring about.

The coke filter designed by Professor Dunkelberg for a Bohemian brewery, and that constructed by Mr. Wedekind for an asylum in Westphalia, have been working for some years to good purpose, and at very moderate cost. The capital outlay for a filter to deal with 48,000 gallons per day was £240, and the renewal of the coke at the end of ten months cost £28. Tests of the filtrate were made at intervals of two days. When the coke was removed, it was found to be coated with deposits of iron oxide, magnesium silicate, and lime. There was no odour, however, showing that the coke had not become fouled after a long period of working.

Mr. Wedekind considers that coke filters can be used to the best advantage in non-submerged beds. The raw water is distributed by sprinklers, and flows clear away from below, so as to allow air to penetrate through the bed. Layers of sand may be interposed to retain fine silt and to moderate the speed of filtration. The alternative of prefiltration is worthy of consideration. Hard waters may be softened by mixing the coke with kieselguhr, which decomposes the salts of lime and magnesia, and leaves insoluble silicates of these bases. Coke itself contains a little siliceous ash, which acts in the same way as kieselguhr, but as a rule the quantity is insufficient for the purpose. Iron also is withdrawn from the water, being oxidized by the occluded oxygen.

FORM OF CONTRACT BETWEEN WATER UNDERTAKERS AND CONTRACTORS FOR SUPPLYING, ERECTING, AND MAINTAINING, MECHANICAL FILTERS FOR THE PURIFICATION OF WATER-SUPPLY TO A COMMUNITY.

1. The contractors hereby agree and bind themselves and their successors, whomsoever these may be, to provide and erect mechanical filters, with all requisite apparatus for their working, valves, filtering material, pumps, and everything necessary for the performance of the filtering work as shown in the specification supplied herewith. The whole is to be furnished

in a workman-like fashion, and strictly in accordance with the specification and estimate, which are here held as repeated, and construed as a part of these presents.

2. The apparatus, when complete, shall be capable of filtering at least gallons per day of twenty-four hours in a regular manner.

3. The water undertakers shall provide the buildings for the reception of the filtering plant, and shall construct foundations according to the specifications of the contractors; and the contractors shall satisfy themselves as to the sufficiency of the work when finished, and by their acceptance thereof shall be held to have accepted them as unobjectionable.

4. On the completion of the buildings and foundations, the contractors shall be bound to erect and complete the installation of the filters within months. They shall carry out the various parts of the work to the satisfaction of the engineer appointed by the water undertakers.

5. The contractors bind themselves and their successors whomsoever, in fulfilment of the guarantee already given, that the filters installed by them for the service of the water undertakers shall be capable of effecting sufficient purification of the raw water, so that the filtrate shall be accepted by the Public Analyst and Bacteriologist as suitable for domestic supply, and wholesome in all respects. In particular, the contractors bind themselves and their successors whomsoever that the following minimum standard of purity shall be attained by the water which has been treated in their filters installed by them at the water undertakers' station:

(*a*) The filtered water shall be clear of suspended matter and from colour, whether arising from peaty matters or otherwise, to such extent that a platinum wire of $\frac{1}{25}$ inch diameter shall be discernible to a person of normal vision when placed at a depth of 6 feet in the filtered water at midday.

(*b*) The number of bacteria per cm^3. of the filtrate capable of growing on gelatine, and counted after forty-eight hours' incubation, according to the usual laboratory practice, at 18 to 20° C., shall not exceed 100, irrespective of the number present in the raw water at any time or season. The filtrate shall be so purified bacteriologically that no typical bacteria of sewage—and, in particular, no *B. coli*, no *B. typhosus*, no *B. enteritidis sporogenes*, nor cholera vibrio, nor the bacillus of dysentery—

can be detected in 40 cm^3. of the filtrate when incubated on the usual culture media for two days at 37° C. It is to be understood that samples shall not be drawn from the filters within an interval of ten minutes after cleaning.

(*c*) The filtrate shall be free from taste and from odour when heated to 37° C.

(*d*) The filtered water shall not contain a residue of any coagulant added to the raw water that can be detected by ordinary chemical analysis in the filtrate, unless the Public Analyst is satisfied that such residue is innocuous to the consumers.

(*e*) The filtrate shall not have an acid reaction under any circumstances.

(*f*) The filtered water shall be suitable for all dietetic and household purposes.

6. The water undertakers shall be entitled to take samples of the effluent from the filters, and to submit these to analysis; and if it be proved to their satisfaction that one or more of such samples has failed to attain the standard of purity specified in paragraph 5 above, within months of the completion of the contract, they shall be entitled to reject the apparatus and to claim the refunding of any sums paid on account. The samples shall be taken and submitted to analysis under the direction of the Medical Officer of Health or any person appointed by the undertakers.

7. The contractors shall supply written instructions for the guidance of the officials of the water undertakers, so that they may be fully informed as to the management of the plant. They shall provide a competent person to instruct the servants and employés during a period of two months after the filters have been put into operation.

8. The amount of water required for washing shall not exceed per cent. of the whole supply. Wash water shall include the quantity actually employed to scrub the filtering material, and in addition any water run to waste after cleaning, until such time as the filter regains its normal efficiency.

9. The contractors shall uphold the plant for the space of one year, and make good defects in so far as these are due to the use of improper materials or to imperfect workmanship.

10. The contractors shall make arrangements for treatment

of the wash water by sedimentation or otherwise, as agreed upon, in such a manner that the effluent shall cause no nuisance when discharged into the watercourse specified.

Other general conditions of contract, dealing with the consequences of rejection of the apparatus owing to its unsatisfactory working during the guarantee period, or with arbitration in cases of dispute, are here expressly omitted, as being of a legal rather than technical character, and therefore outside the province of the present book.

PURIFICATION OF WATER BY CALCIUM HYPOCHLORITE.

For some time attempts have been made to find a chemical which would sterilize water when added in small quantity, and leave no residue that might not be easily rendered harmless to the consumer, and imperceptible to taste or smell. Dr. Phelps of Boston and Dr. Thresh have recommended the use of chlorine or hypochlorite of calcium, chemicals which possess great bactericidal potency. Chlorine and hypochlorites have been used in times of emergency to destroy the pathogenic germs that might possibly have found their way into the service water. But as chlorine is easily held in solution by water, and as a very small proportion of that gas in solution produces a disagreeable effect on the palate, there has always been a disposition to make the use of this disinfectant as brief as possible.

If the crude water is fairly free from suspended matter of an organic nature, 1 part of chlorine per 1,000,000 serves to destroy all germs. Laboratory experiments show that thousands of noxious bacteria may be added to a tumbler of filtered water, but that 10 to 15 drops of chlorine water or of hypochlorite solution stirred into it will extinguish every trace of life. The cost of treating water with hypochlorite would not exceed five or six shillings per 1,000,000 gallons, so that the process would certainly find favour if only a simple means were at hand for eliminating all chlorinous residues in the service water.

One procedure which has been tested is to add to the treated water an appropriate amount of bisulphite of soda, whereby the chlorine is brought into a harmless combination. The cost per 1,000,000 gallons of applying the bisulphite would be rather

more than a shilling (see Dr. Thresh's article, *Lancet*, November 28, 1908). In a communication to the Seventh International Congress of Applied Chemistry, Dr. Thresh referred to a method of disposing of any residual chlorine by filtration. A thin layer of iron turnings serves to absorb all traces of chlorine. After a few hours' working the iron is apt to become coated with loosely adherent oxide, which requires to be removed by washing. A very little iron is also brought into solution, and this is easily retained by a layer of polarite.

Further experiments have shown that under certain conditions of the raw water the chlorine is not absolutely eliminated by contact with iron. But filtration through a bed of charcoal disposes of it completely. The water, after treatment with the chemical is brought to a tall drum, where it passes first through coarse gravel and sand, and then through 16 inches of coke, carbon, or charcoal, which rests on a "finishing" layer of finer sand.

In relation to this, Mr. Candy has perfected a De Chlor process* which has been adopted at an important municipal waterworks. Very careful analyses have shown that the purified water contains neither *B. coli* (though these are present in the raw water) nor free chlorine, and in all other respects the service water is of excellent quality.

As already mentioned, the success of the chlorine treatment depends in a measure on the condition of the raw water. Organic substances absorb the chlorine, so that the bacteria escape its influence. Prefiltration becomes necessary when the organic matter is in suspension; if it be in solution and irremovable by a coagulant, then more chlorine must be applied. Dr. Thresh instances a deep-well water which was polluted, and to this 1·75 parts of chlorine per 1,000,000 were added to complete sterilization.

Experiments made by Newlands and Stevens with the supplies drawn from the Connecticut River for the town of Hartford, U.S.A., have convinced them of the utility of chlorinated lime for the sterilization of river waters that have been tainted with sewage. Above Hartford the Connecticut receives the drainage of a population estimated at 250,000,

* The De Chlor process is the property of the Candy Filter Company, Westminster, who have protected their rights in connection with it.

and at the intake the germ content amounted to 60,000 per cm^3. at the time of the experiments. The addition of 1·1 grains per gallon of the chemical at the pumping-station reduced the bacteria by 99·8 per cent. (*Engin. Record*, vol. lxi.).

Commenting on the procedure at Hartford, Guth (Hamburg) observes that a considerable saving of the sterilizer might be effected by applying it after filtration, as the organic matter removable by that step always absorbs some portion of the available chlorine.

Appliances similar to those in use for introducing other chemicals would serve for hypochlorite. Commercial hypochlorite of lime containing about one-third of its weight of the active element, chlorine, costs £5 to £6 per ton. Of this, 30 pounds would in general suffice for 1,000,000 gallons. A day's charge could be dissolved in a tank, and fed to the raw water by pump or otherwise, as decided upon. The chlorine does its work in twenty to thirty minutes. The outlay on hypochlorite forms the main part of the working expenses, as the washing of the filter of iron turnings gives no trouble, the oxide adhering loosely.

On the whole, it must be said that a very serviceable and most effective mode of purification has been described. It would seem to be perfectly applicable to river supplies which carry little sediment, and to stored waters drawn from wells or streams. The large capital outlay involved in bringing upland water from a long distance may thus be avoided. All danger from water-borne germs of disease is put aside, without in any way marring the potability of the supply.

FERROCHLORE PROCESS OF STERILIZATION.

Somewhat similar to the hypochlorite treatment is the application of a mixture of bleaching lime and chloride of iron. The water is supposed to hold some carbonate in solution in order to bring about the necessary reaction for developing the precipitant. The active bactericide is chlorine, which is loosely combined in bleaching powder as hypochlorite. The simultaneous precipitation of oxide of iron facilitates the removal of impurities on the filter-bed.

Of chloride of iron, 8 parts per 1,000,000 are added, and of bleaching lime sufficient to yield 0·1 to 0·2 part per 1,000,000

of chlorine. The dose would, however, depend entirely on the character of the raw water, and it is only after sufficient tests that the proper amount to be employed can be determined.

An experimental plant at Paris, dealing with 1,000 gallons per hour, completes the sterilization of the water at a cost of £3 per 1,000,000 gallons. No doubt it would be possible to reduce this cost if the operations were carried out on a more extensive scale.

The elimination of chlorinous odours is left to the settling tanks, but, as chlorine is quite soluble in water, it would be advisable to adopt a plan similar to those alluded to in connection with the calcium hypochlorite process in order to get quit of traces of chlorine.

CHAPTER VIII

PURIFICATION OF WATER BY OZONE

THE destructive action of ozonized air upon bacteria in water having been demonstrated by Ohmüller and others, Messrs. Siemens and Halske, of Berlin, undertook experiments on a large scale, and were successful in devising a plant which would sterilize a continuous supply of many cubic metres per hour. In order to economize the expenditure of ozone, it was found expedient to filter off the greater part of the suspended matter, so as to eliminate the inert organic substances which are ready to undergo oxidation. This was in 1898. The first municipalities which were ready to step aside from custom, and adventure upon the new and scientifically approved system were Paderborn and Wiesbaden. The capital outlay was considerable, and the working costs were high. Yet these communities had no cause to regret their choice. The scourge of enteric fever, which had in former days paid them repeated visits, is now practically unknown among these users of ozonized water.

While the Berlin firm was thus engaged in advancing the process to a commercial footing, M. Tindal was experimenting with his apparatus at Brussels, Paris, and elsewhere. He succeeded in finding an introduction for it at some less important places. He materially reduced the working costs. Tindal's patents have passed into the hands of M. de Frise, who has added many improvements, and has brought to great perfection an installation now established at St. Maur. There also may be seen the Otto system of ozone treatment, which has been adopted at Nice, where it is working on a large scale.

Not a few patents have followed in the wake of the devices mentioned, and some have been put to the test in America. Naturally, a purification process which converts an unwholesome stream into a liquid as certainly inoffensive as the purest

water is one that appeals directly to water undertakers. relieve them of the necessity of tapping distant sources ving costly aqueducts. The effluent from the ozonizer ably more reliable under varying conditions of weather infall than even the drainage of surface water from ess mountains. With recent improvements, the capital compares favourably with that of other purifying es. Great reduction has been effected in the working es, and further economies may be looked for. The ıer cannot find fault with the treatment, for no residue

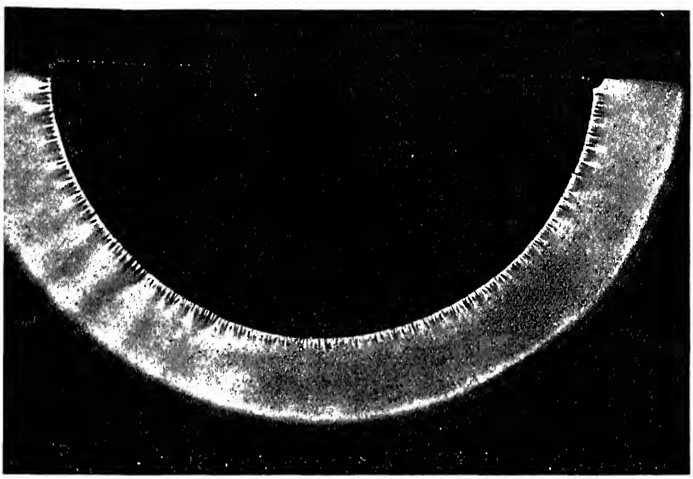


FIG. 46.—BRUSH DISCHARGE.
(By permission of M. de Frise, Paris.)

purifying agent is left in the tap water. In the words lebrated English expert on sanitary requirements, it is eal procedure."

od of generating Ozone.—Ozone is most conveniently ed from the air by means of the silent discharge of high- electricity—as, for example, from the terminals of on machines, and of secondary coils and transformers . voltage. The apparatus employed may or may not a dielectric (non-conductor), such as glass, in the path lischarge. This discharge proceeds from points in some f instruments, and from smooth surfaces in others.

Designers of ozonizing apparatus must provide against "sparking" between terminals, so as to avoid the formation of the oxides of nitrogen, which are corrosive. According to Warburg (*Annalen der Physik*, 1906, No. 9, p. 734), there is always *some* oxide of nitrogen formed. As a rule its amount is trifling, but quantities which might be regarded as traces hinder the formation of ozone. One part of nitric peroxide (NO_2) in a thousand parts of air prevents the condensation of oxygen into ozone altogether. In consideration of this, experimenters have always sought to obtain a silent, brush-like discharge, such as is represented in Fig. 46. Air exposed to the noiseless bombardment proceeding from a body in high electrical tension is ozonized; that is to say, some part of the

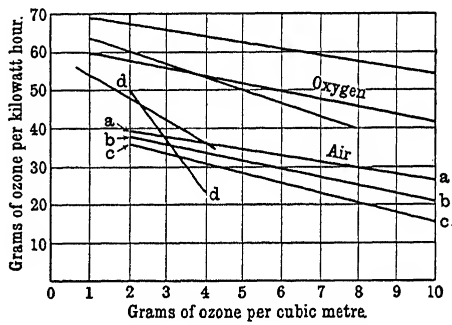


FIG. 47.—COMPARATIVE YIELD OF OZONE FROM AIR AND FROM OXYGEN.

oxygen, which is normally a molecule formed of two oxygen atoms, O_2, is made to assume the more active molecular grouping, O_3.

The yield of ozone is much larger if pure oxygen is passed into the ozonizer in place of air. Warburg investigated the question from this point of view, as did Dr. Erlwein and a representation of the results is given in Fig. 47. The unit of power in this case is the kilowatt, which is rather more than $1\frac{1}{3}$ horse-power.

Importance of operating on Dry Air.—For good efficiency, the air which is sent to the ozonizer must be dried. If the aqueous vapour always present at ordinary temperatures be not removed, the water molecule H_2O is impelled by the electric stream to attach to itself another atom of oxygen, and

so become H_2O_2—peroxide of hydrogen. This body has also germicidal powers, but it is more liable than ozone to persist in the treated water as a residue, and it is on that account less to be desired as a sterilizer. Besides, when the air is moist, even to a slight degree, the output of ozone corresponding to a given expenditure of electrical energy is lowered. Warburg found that the production of ozone fell off quickly as the tension of the water vapour content increased. Calling the output of ozone in dry air under given conditions 100, the production is diminished 20 per cent. when the pressure of the aqueous vapour contained is equivalent to 7 centimetres (about

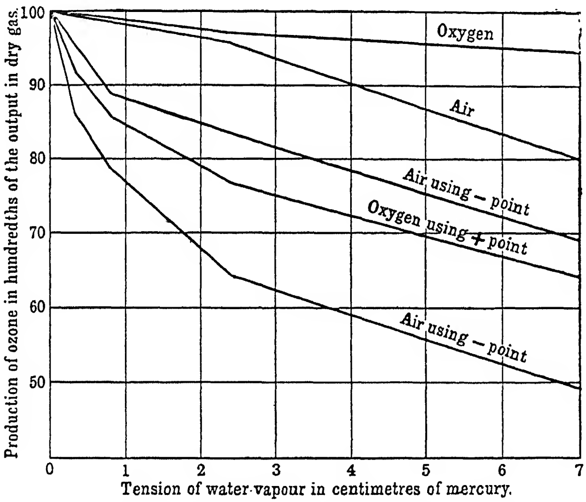


FIG. 48.—DECREASE OF OZONE PRODUCTION IN MOIST AIR.

3 inches) of mercury. The falling off is more apparent if the electrical discharge issues from points instead of from a surface, and in that case the output may be only one-half with the same tension of vapour. Fig. 48, which is reproduced from Warburg's determinations, shows the results graphically for a range of aqueous vapour pressures.

Desiccation of the air may be effected by passing it over substances which absorb moisture, such as caustic lime or chloride of lime; or, alternatively, it may be cooled to freezing-point, when nearly the whole of the aqueous vapour condenses.

High Voltages necessary.—When the ozonizer is electrified with a current whose voltage is caused to rise gradually, it is observed that there is no evidence of ozonization until the electrical pressure has risen to several thousand volts. The starting-point of the ozonization differs with the build of the apparatus, but, roughly speaking, it may be placed at 10,000 volts. As the electrical tension is increased, the production of ozone increases in proportion to the square of the voltage. M. Chassy of Lyons found, under certain conditions, that with a voltage of 20,000 there was formed 232 milligrammes of ozone, while with 40,000 volts the output rose to

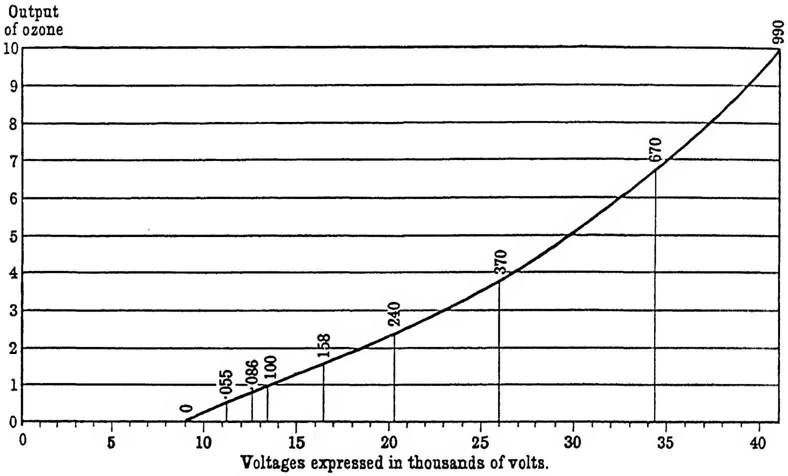


FIG. 49.—OUTPUT OF OZONE WITH INCREASING VOLTAGE.

945 milligrammes. Various results obtained by this experimenter are plotted in Fig. 49. The results of Fig. 49 and also those given in Figs. 51 and 53 have been confirmed by M. de Frise, Paris.

Increased Production at Low Temperature.—A low temperature is favourable to ozonization. It is well established that ozone becomes unstable under the influence of heat, and at a temperature of 270° C. it decomposes wholly. It is accordingly economical to keep the air entering the ozonizer at as low a temperature as possible. Warburg and Leithäuser examined this question, working at temperatures between 20° C. and 80° C. Their results are graphed in Fig. 50.

Concentration.—The amount of ozone per cubic metre of air is known as the "concentration." As the content of ozone increases, so does the difficulty of producing more within the

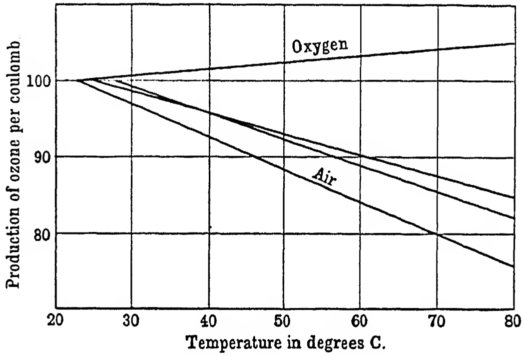


FIG. 50.—DECREASE OF YIELD OF OZONE AT HIGH TEMPERATURES.

same volume. In truth, when the concentration has gone to a certain length, the electric discharge tends to decompose some of the ozone already formed. Fig. 51 represents the results of a series of experiments by M. Chassy. It is clear

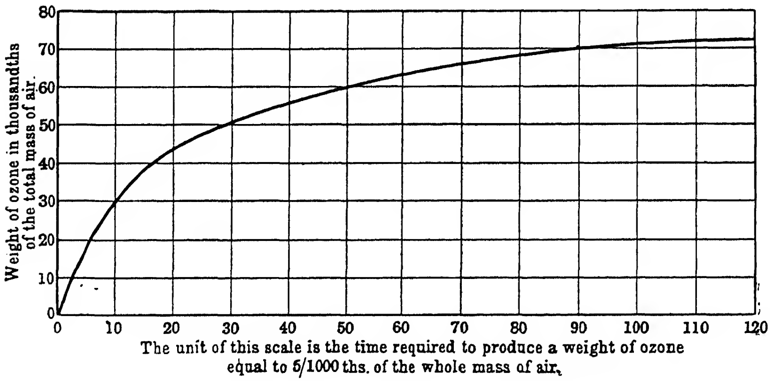


FIG. 51.—DECREASE OF OUTPUT OF OZONE AS THE CONCENTRATION RISES.

that the conversion of oxygen into ozone goes on slowly after the discharge has been at work for a time. Eventually the increase is barely noticeable.

Under favourable conditions of temperature, dryness, and voltage, it is not possible to push the concentration beyond a certain limit. M. Chassy found that the maximum was about 22 grammes of ozone per cubic metre—that is, 1·75 per cent. But to attain to that maximum, he was obliged to expend four times as much electrical energy as was needed to give 11 grammes per m^3., and nearly eight times as much as was required to bring about a concentration of 3 grammes. These results of M. Chassy's are depicted in Fig. 52. Fischer and Braehmer proved that the output of ozone per voltampère

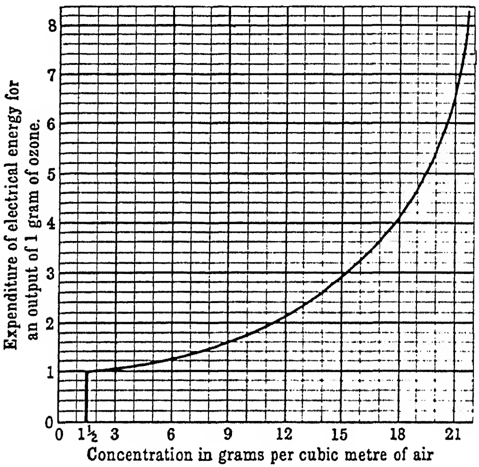


FIG. 52.—LIMITS OF THE CONCENTRATION OF OZONE.

could be doubled by reducing the concentration in the ratio of 5 to 4.

Obviously, economy in the employment of ozone for sterilizing leads to the application of air with a low concentration. At large installations a concentration of 1·6 to 1·8 grammes per m^3. is quite usual. The lowest costs have been reached at one important station by regulating the speed of the air-feed so as to secure a concentration of 1·6. The current was one of 110 volts, whose tension was stepped up to 36,000 volts by means of a transformer.

Regarding the output of ozone per horse-power employed, it appears that 25 to 30 grammes per hour is a common average rate of production. To obtain this quantity, the concentra-

tion must be kept down to 1·8 or 2 at most. With a concentration of 8 grammes per m^3., the hourly yield per horse-power falls to 15 grammes.

There are thus three points which deserve special attention in the manufacture of ozone on a commercial scale :

1. The concentration should be low (Figs. 51, 52).
2. The air entering the ozonizer must be dry (Fig. 48).
3. It should be kept cooled (Fig. 50).

The Avoidance of Sparking.—It has been said that the discharge of electricity through the stream of air which is led between the poles of the ozonizer is brought about by transforming the ordinary current into one of high voltage. High voltages lead to sparking across the air-space, with the formation of nitrous and nitric bodies. Other things being equal, that ozonizer is to be preferred which either prevents or can be adjusted to prevent the inconvenience of sparking. Movable resistances, consisting of tubes filled with glycerine, are included in the circuit at several stations. By means of these the external resistance may be at once increased if sparks appear, and a proper adjustment of the number of glycerine tubes in circuit is found to be an efficient remedy.

According to Fischer and Braehmer (*Berichte Deutsch. Chem. Gesellsch.*, 1905, No. 11), a limit is set to the voltage that may be employed in any case, because of the elevation of temperature which follows a rise of electrical tension. Consequently, the ozone molecule becomes unstable, and some part of the yield decomposes.

Ewell has published his researches on the behaviour of insulating media or dielectrics (*Physical Review*, 1906, p. 232). It appears that ozonizers act to better advantage when such insulators as glass, shellac, mica, are interposed between the poles. Glass is most commonly employed in practice. Large electrodes are less efficient than small ones, and the latter are more easily replaced should a breakage have occurred.

The System of De Frise.—The efficiency and the reliability of this system have been put to very searching tests at St. Maur by Professor Besançon, Drs. Ogier, Bonjean, Miquel, Levy, and others, in connection with the investigations relative to the Paris water-supply. In 1908, Dr. S. Rideal, of London, visited St. Maur, and carried out experiments on an extensive scale.

His views of this method of purification were fully detailed at the meeting of the Royal Sanitary Institute in January, 1909. He approved of the system, and found that the bacteriological results were all that could be desired. There was also a reduction of more than 40 per cent. of the organic matter, as judged by the oxygen-consumed standard. The effluent had its full content of dissolved oxygen, and was clear and sparkling in appearance.

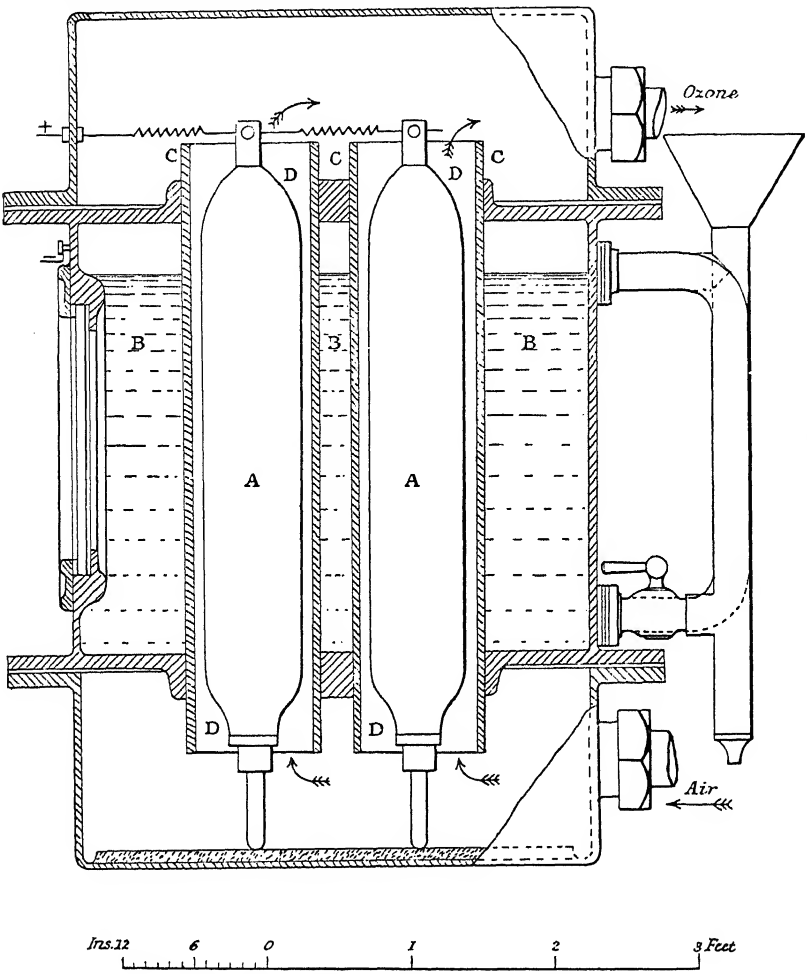


FIG. 53.—SIEMENS-DE FRISE OZONIZER.

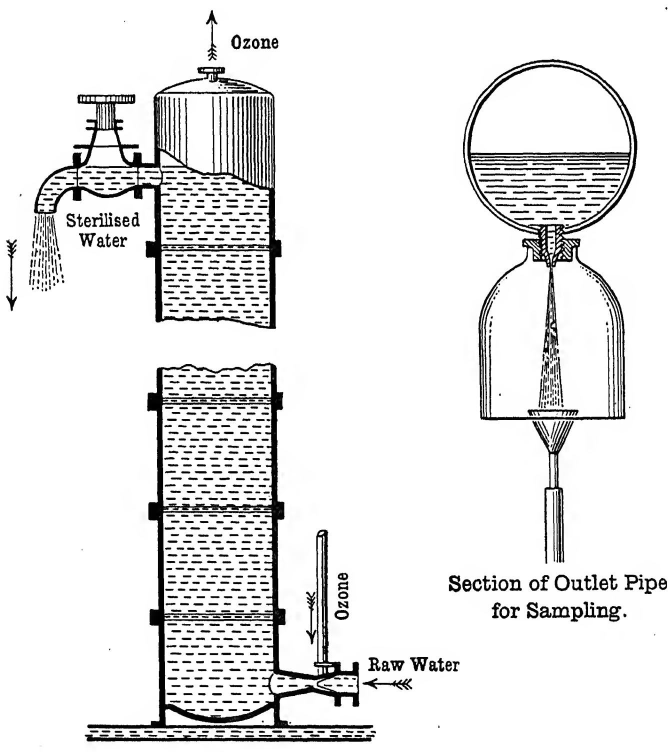
There are two distinctive features of the mechanism which are specially interesting — namely, the Siemens-De Frise ozonizer and the De Frise sterilizer. The former is designed to encourage the ready formation of ozone by virtue of silent discharge, without any yield of oxides of nitrogen. The latter makes certain that the whole volume of water treated shall be thoroughly exposed to the ozonized air.

The ozonizer is shown in transverse section in Fig. 53. It is a cast-iron box divided horizontally into three compartments by metal partitions. These are pierced to receive the glass tubes C, C, which are packed in water-tight by means of screwed glands, so that the middle chamber, which acts as a water-jacket to the tubes, is quite cut off from the top and bottom compartments. The latter communicate with each other by way of the glass tubes, but only to such extent as is permitted by the annular space lying between the walls of each tube and an aluminium cylinder, A, which lies therein concentrically. Each aluminium cylinder is carefully insulated from the metal box, and is separated from the glass tube in which it stands by the annular space referred to, and that is about $\frac{1}{16}$ inch wide. There are eight tubes in each box, all adjusted in the same way as the two shown in section. It will be understood that when the aluminium cylinder is kept at high potential, while the box and enclosed water are to earth, a strong field of force is set up within the annular space. The silent discharge favourable to ozonization is established, and a slow current of air, passing from the lower to the upper compartment, carries away a charge of ozone. In the illustration the air takes the course indicated by the arrows.

The upper extremities of the aluminium cylinder are joined to the insulated pole of a step-up transformer which is employed to raise the voltage from about 100 to nearly 40,000. The other terminal of the transformer is earthed. During the tests made at St. Maur, the ozonizers were excited by an alternating single-phase current at a pressure of 36,000 volts.

Sterilizing Towers.—The sterilizer in service there is an iron tube some 25 feet in height, and about 1 yard across, built up of sections with collar-joints, as illustrated in Fig. 54. These sections are 20 inches or more high, and they are enamelled on the inner surface. On the upper circumference of each rests

a sieve of celluloid, which is suitably held in position after having been brought to a true level. The perforations of these sieves are minute holes $\frac{1}{40}$ inch in diammeter, and they are closely set over the whole surface, so that a column of water passing through the cylinder is split up into a vast number of fine jets every time it encounters a sieve. This it does eight



Section of Steriliser.

FIG. 54.—STERILIZER AT ST. MAUR.

or ten times in travelling from one end of the sterilizer to the other. The practice here is to make the water pass upwards, and along with it goes a current of ozonized air, which is transmitted from a compressor placed in train with the ozonizers. The cycle of operations is indicated in Fig. 55. From the diagrammatic view of the arrangement, it will be readily understood how the various operations are co-ordinated.

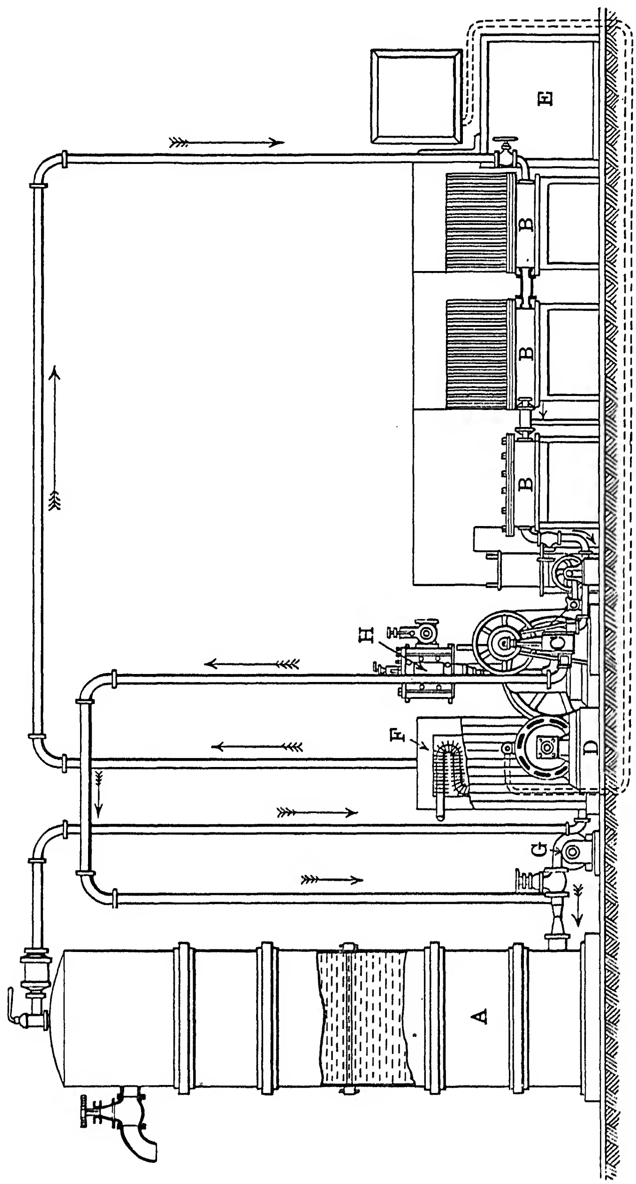


FIG. 55.—SYSTEM SIEMENS-DE FRISE.

A, sterilizing tower; B, ozonizer; C, compressor; D, alternator; E, transformer; F, despicator (by cooling); G, motor.

The volumes of water and ozonized air which interact at the St. Maur installation are in the ratio of 100 : 40, this proportion having been found to give satisfactory sterilization. The action of the sieves is to break up both air and water, and bring them into intimate contact. By means of spyholes placed at various heights, it is seen that there is considerable commotion and scrubbing at the sieves, the water and air competing for the passage of the minute apertures. As the air-bubbles ascend, they become noticeably smaller, this being due in part to further subdivision, and also to the solution of the ozone and other gases. As the pressure within the cylinder is from one-half to three-fourths of an atmosphere in excess of the normal, the solution of gases in the water is much facilitated.

With the proportion of air and water given above, it is found that about 80 per cent. of the available ozone is consumed in the work of sterilization. The bubbles which escape from the top of the water column contain the remaining 20 per cent. The air which collects in the dome of the sterilizer is led away to a drying apparatus by the conduit indicated in the figure, and from thence to the ozonizer, so that no loss of the purifying gas is incurred. The drying apparatus consists of a separator (to remove condensed moisture) and a desiccator charged with chloride of calcium. Additional supplies of air are admitted very frequently through a suction valve at the inlet to the separator, so as to compensate for loss in the sterilizer. In warm weather the desiccator and the ozonizer require to be kept cool.

The whole apparatus thus consists of—

1. Sterilizer, A, 25 feet high.
2. Double-acting air-pump, C, to maintain the air-circulation.
3. Centrifugal pump, G, to inject the water.
4. Battery of ozonizers, B; six to nine sets in operation.
5. Separator and desiccator, F.
6. Alternator, D.
7. Step-up transformer, E.
8. Motor, H.

Power required for the De Frise System.—Steam-power brings the alternator into operation, and the energy absorbed in the ozonizers per 1,000,000 gallons amounts on the average

to 60 B.T.U. To this there is to be added 75 B.T.U., representing the work done in pumping. Thus, the expense of energizing the De Frise cycle, calculated *pro rata* with the charges in Paris, is about £3 5s. per 1,000,000 gallons. But the Chief Engineer of the Paris Municipality calculates that the cost would not go beyond half of that sum were the electrical supply rated at what it may eventually cost at St. Maur—viz., 0·055 franc per kilowatt hour.* This figure will be arrived at, he anticipates, when the plant is increased so as to treble the output of sterilized water.

The air entering the sterilizer is found to carry a charge of ozone which is very nearly constant, and on the average the content is 1·6 grammes per m^3. Seeing that 1 m^3. of ozonized air is drawn in with $2\frac{1}{2}$ m^3. of filtered water, it follows that the actual weight of ozone applied to each m^3. of the intake is 0·64 gramme.

Treatment of River Water, and the Results.—To come to the changes effected upon the roughly filtered Marne water :

1. The rough preparation consists of leading the raw water into sedimentation basins, and from these to sand-filters. The effluent from the latter carries at times as many as 300 bacteria per cm^3., and not infrequently *B. coli* is discoverable when 40 cm^3. at a time are searched. The colour is dull, with a brown to greenish hue. On the other hand, the water which is delivered by the sterilizer is bright and sparkling—highly transparent, indeed, with only a faint bluish tinge.

2. In order to dissipate any odour of ozone, the effluent is led into a collecting tank with three compartments, all enamelled internally. It passes from the first to the second compartment through submerged openings, and so onwards to the third. At the issue from the sterilizer there is a perceptible odour, but that has almost entirely vanished before it is ready to flow away from the last compartment.

3. There being no increase of nitrates in the ozonized water as compared with the filtered, it is evident that oxides of nitrogen cannot be produced in the ozonizer. Nor are there any nitrites, chlorine compounds, or any peroxide of hydrogen, traceable to the electric discharge. These are the conclusions drawn by Drs. Ogier and Bonjean (1904), and by Dr. Rideal (1908).

* See p. 219.

4. It was found by the two French savants referred to that the amount of free oxygen does not augment in any great measure during the De Frise cycle. This was hardly in accordance with what one would have anticipated, nor did it agree with the experiences of those who had tested other systems of water treatment by ozone. Dr. Rideal drew quite a contrary inference, but it is to be noted that the filtered water during the tests made by Dr. Ogier and his colleague was unusually well aerated, often holding nearly its full complement of oxygen. That was not the case in the autumn of 1908, when Dr. Rideal made his researches. He found that the oxygen content was increased from 4,450 cm^3. per m^3. to 6,200 cm^3., this indicating the average of twelve experiments. Drs. Ogier and Bonjean had previously concurred in the expectation that with poorly oxygenated waters an absorption of oxygen would take place.

Importance of Good Aeration; Oxidation of Organic Matters.—Dr. Rideal lays much stress upon the aeration of potable waters, for he reasons that a water poor in oxygen is suspect, seeing that the decomposition of organic matters occurring would drain off a part of the dissolved oxygen. Referring to the *Analyst*, August, 1901, it is stated in a paper by Dr. Rideal that a well-known expert in water and sewage purification maintains that "if the aeration in polluted waters fell below 50 per cent., the organic matter was nourishing aerobic bacteria, and oxygen was being used up more quickly than it could be taken in from the air. But if 50 per cent. or more of aeration were present, showing tendency to increase, then the sample was on its way to purification."

The French experts, in their 1904 report, say that the reduction of organic matter during the sterilization is very slight. They look upon the organic substances in the filtered Marne water as being of a rather stable type. They have already resisted the oxidizing action of the dissolved air, and consequently an exposure of a few minutes to a limited quantity of ozone could not push the combustion very much farther.

In connection with this question, Dr. Rideal applied the oxygen-consumed test with permanganate, and came to the conclusion that the reduction of the organic matter was

over 40 per cent. This average was struck from fourteen determinations. It must be noted that the oxygen-consumed figure varies from month to month within pretty wide limits, and that the average reduction might differ considerably for another set of tests.

That there is actually an oxidation of organic matter in the sterilizer was otherwise confirmed by Dr. Rideal. One of the products of the interaction with oxygen is CO_2, and this was found to have increased during the passage of the water through the sterilizer, and that by an amount which corresponds very closely with that which was indicated by the consumed oxygen. It was observed that a further oxidation of organic matter proceeds in the compartments of the collecting tank. This, it may be inferred, is due to the residual ozone carried away by the effluent.

Bacteriological Results.—Since the year 1905 rigorous measures have been adopted at St. Maur to exclude *B. coli* from the service water (see p. 288). We have said that the filtered Marne water usually gives distinct indications of *B. coli*. After the De Frise purification only two or three microbes per cm³. survive, and these are of the harmless type—viz., *B. subtilis*, *B. mesentericus*, yeast, mucor. No trace of *B. coli* remains even when volumes up to ½ pint are searched. This is confirmed by numerous reports from analysts of repute. That being so, it may safely be concluded that the more easily destroyed pathogenic bacteria—*B. typhosus*, for example—are absent. The following is a sample analysis :

TABLE XII.

	Filtered Water: Colonies per cm³.	The Same Water after Ozonizing.	*B. Coli* in Filtered Water. per cm³.	*B. Coli* in Ozonized Water. per cm³.
January 31 ..	1,815	3	1 in 35	0 in 480
February 1 ..	825	1	0 in 35	0 in 480
February 2 ..	150	1	3 in 120	0 in 480
February 3 ..	470	1	1 in 100	0 in 480
February 4 ..	270	2	1 in 100	0 in 480

In his earlier installations De Frise made use of an ozonizer without dielectric, and he only abandoned it because the Siemens type is more economical. For small plants it is still

recommended by its inventor. Essentially it consists of a semicircular trough laid horizontally upon its curved surface, and closed in above by a glass plate. From the plate are suspended a number of half-round saws dipping nearly to the inner circumference, and connected above through suitable resistances (glycerine tubes as a rule) to one pole of a transformer. Fig. 56 represents one of the saw edges which emit the silent discharge, and Fig. 57 shows a vertical section of the complete ozonizer.

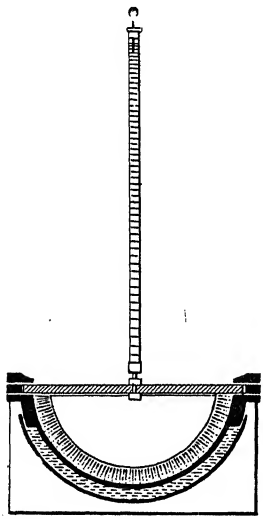


FIG. 56. — SEMICIRCULAR ELECTRODE SHOWING WATER-JACKET (CROSS-SECTION OF FIG. 57).

Up to the year 1910 the De Frise system had been in operation at St. Maur in an experimental way, but the members of the Conseil d'Hygiène of the Department of the Seine were so well satisfied with the results of the ozone treatment that they agreed to recommend the process on a large scale for the purification of water to supplement the general supply of Paris. Alongside of the De Frise installation, that of the Compagnie Générale d'Ozone (London agents: the Lahmeyer Electrical Co., Ltd.) was established, and this also was fully approved. The capital outlay for the latter were reckoned to be slightly higher than in the case of the De Frise system, but working costs were practically equal. The Conseil Municipal de Paris, after hearing the opinion of the Conseil Supérieur d'Hygiène, authorized that a sum of about £30,000 should be paid to the two companies for an installation which is to deal with 20,000,000 gallons daily, the work being equally divided between them.

The Marne water requires preliminary filtration, and it is proposed that this shall be more rapid than is usual with ordinary sand-filters, and it is believed that 8 inches per hour may safely be attempted. The new filtering-beds are estimated to cost £60,000, and the sum of £112,000 has been voted to cover the whole expense of this important addition to the

water-supply. It is calculated that the working costs will be brought down to 0·35d. per 1,000 gallons.

The Vosmaer System of Ozone Purification.—The invention of Vosmaer relates to the ozonizer, and is intended to cope with

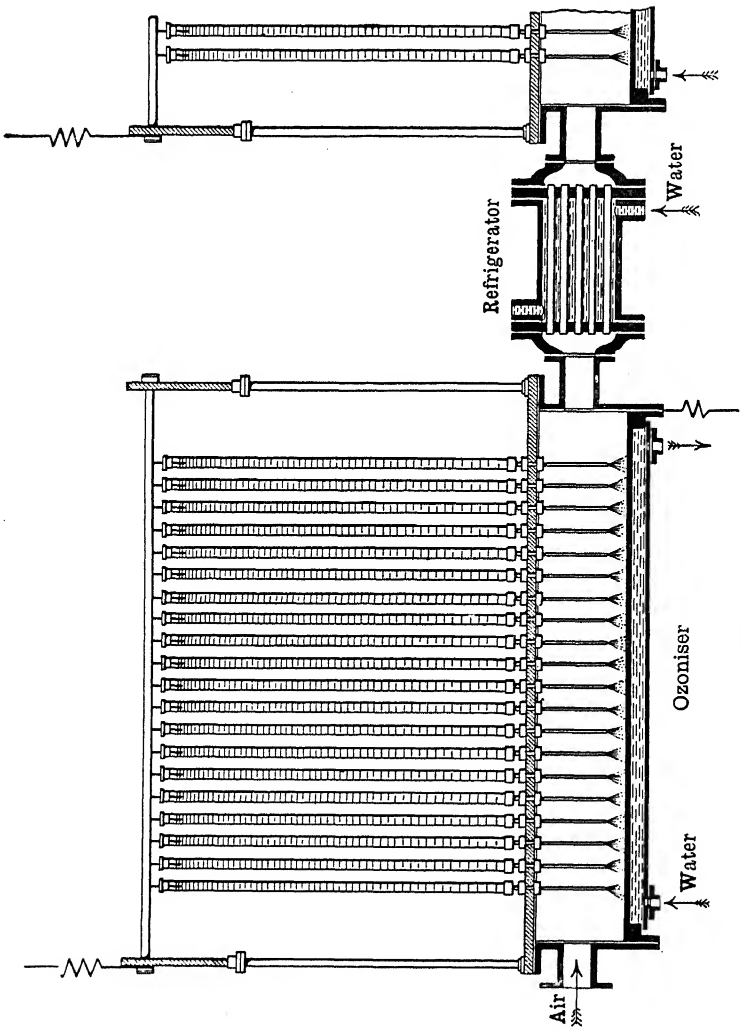


FIG. 57.—DE FRISE OZONIZER WITHOUT DIELECTRIC.
(By permission of M. de Frise, Paris.)

the difficulty of obtaining a suitable dielectric for the ozonizer. The construction is as follows: An iron tube is provided with a strip of metal which is fixed along its length inside, and

insulated on porcelain supports. The breadth of this strip is such that its free edge does not reach the central line, towards which it is directed. This edge is cut into teeth like a saw. Such a tube forms one element of the Vosmaer ozonizer, which is built up of a large number of similar pieces, as shown in Fig. 58. This represents a Vosmaer "battery" in which the tubes are seen to lie parallel, so that the stream of air to be ozonized is divided amongst them. Each saw-edged strip is connected to one pole of a high-tension transformer, and the tubes are connected to the other. An alternating current is used. No dielectric is employed other than the air which is to feel the effect of the silent discharge.

The sterilizing tower (Fig. 59L) is a tall chamber filled with gravel or small pebbles, and the raw or roughly filtered water is sprayed over the top, and percolates downward. Ozonized

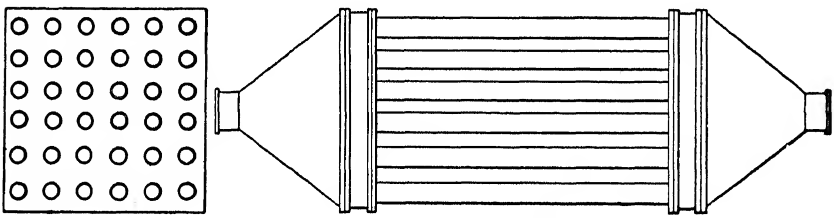


FIG. 58.—VOSMAER OZONIZER.

air is forced in from below, and, ascending through the supporting grid, encounters the water threading its way among the gravel. This method serves to bring about an intimate and fairly prolonged contact between the water and the ozone.

The whole arrangements are represented diagrammatically in Fig. 59. The plant was formerly in use at Philadelphia for treatment of a private supply from the Schuylkill, which is more or less polluted. The raw water is first filtered, or rather strained, and it brings into the sterilizer numerous bacilli of an undesirable species, together with no little organic matter. The output from the tower is, on the other hand, so far as concerns bacteriological purity, almost in a perfect condition. The organic content is reduced by about 50 per cent. on the average. As regards the energy absorbed, this amounts to close on 200 B.T.U. per 1,000,000 gallons, taking into account both the electrification and the pumping of air and water.

E, raw water; F, pumps; G, reservoir for raw water; H, rapid filter; K, reservoir for filtered water; L, sterilizing tower; M, air-suction tube; N, air-pump; P, drying apparatus; Q, ozonizer; R, tube carrying ozonized air; S, reservoir for purified water.

For operating the filter there are valves A, B, C, D.

To clean the filters, A and C are opened, and filtered water flows downwards from the reservoir and traverses the rapid filter from left to right, escaping at T. For filtering A and D are opened and B and C closed. On opening B and closing C a sample of the filtered water may be taken.

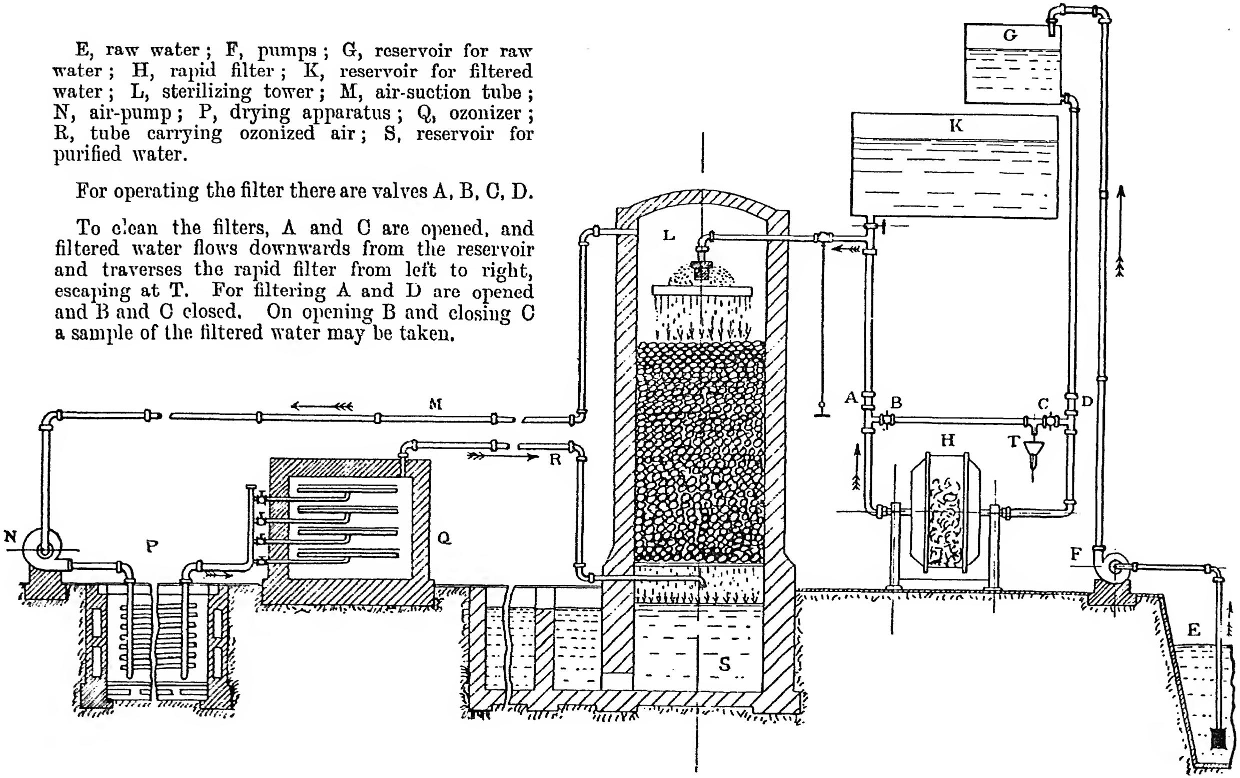


FIG. 59.—VOSMAER OZONIZING PLANT (GENERAL VIEW).

that it has to be elevated 10 or 12 feet, the power required is 4 horse-power, the efficiency of the pump being taken at 0·6.

The energy expended upon the ozonizer would be 12,000 watts, and this figure corresponds to 24 horse-power, taking the efficiency of the transformer at 0·7.

The exciter in connection with the alternator will absorb 1 horse-power.

Total power required : 29 horse-power.

The plant required to deal with the above output is as follows :

1. Centrifugal pump.
2. Single-phase alternator with exciter, 500 cycles, 200 volts.
3. Distributing board, complete with instruments for control and measurement.
4. Single-phase transformer, 500 cycles, 250 to 15,000 volts.
5. Seven-element batteries of ozonizers for 220 grammes ozone.
6. Two groups of emulsers composed each of 100 aspirators in cylindrical iron box with enamelled interior. These emulsers are mounted in a tank of bonded cement directly over the sterilizing tower.
7. Two sterilizing towers, each of approximately 18 feet by 5 feet internal dimensions. The lower portion of the tower, as illustrated in Fig. 60, holds a small reserve of ozonized water. The outlet is submerged so as to confine the gases, which are carried down with the water, and cause them to reascend amongst the mass of pebbles. From the upper part of the emulser a pipe leads away the gases which tend to accumulate there. It carries them underneath the grid, and distributes them there. The bed of shingle (or smooth, clean pebbles) is 6 feet deep.

Cost.—The capital outlay necessary to cover the above-named apparatus—viz., electrical installation for the ozonizer, pump, sterilizers, and also a shunt-wound motor for the water and air pumps—would amount to not more than £3,000.

The expenditure on forming the site, erecting suitable buildings, and locating the plant therein, is not included in the estimate.

If no local supply of electrical current is available, there would be required an engine and current-generator. These would probably cost £1,000.

Annual outlay, inclusive of labour, power, interest and depreciation, sinking fund, repairs, rates and taxes, may be reckoned at the rate of 0·5 penny per 1,000 gallons as a maximum. This means a yearly expenditure of £700.

At the St. Maur installation, where the Compagnie Générale de l'Ozone is to deal with 10,000,000 gallons, it is estimated that the working costs will not exceed 0·4d. per 1,000 gallons.

Ozone Purification Installation at Ginnekin, Holland.—The purification carried out at Ginnekin is an outstanding example of the astonishing work that can be accomplished by ozone. The raw water operated upon is that of the River Mark, which drains a long stretch of farm lands actively cultivated and periodically manured. In addition, a large number of pits, with water stagnating among decomposing rubbish, discharge their overflow into the Mark, and bring in crowds of undesirable germs. In fact, the appearance of this muddy river, with its yellow-brown tint and the unmistakable flavour of its best samples, might induce one to exclude it from the category of possible sources of supply.

The ozone treatment reverses the vitiated condition of the water, and produces an effluent which is not only to all intents sterile, but is clear, sparkling, and, to use the description of Professor Gerard, appetizing. It has acquired all the properties of the best upland water, from which it is only distinguishable to the chemist from the presence of ammonia, which figures at 0·22 per million, and of chlorine at 16 per million.

The water pumped from the intake is first subjected to a rough filtration through coarse gravel, and afterwards it is more carefully strained through a bed of river sand. The latter is in duplicate, so that at the cleaning, which takes place about once a fortnight, there may be no interruption of the filtration. The area of each sand-bed is 60 square feet, the depth of material is 40 inches, and the effective "head" from 40 to 50 inches. Passing away from the filters, the water collects in a small reservoir, from which it is pumped to a tank situated at the top of a masonry tower (Fig. 61), 100 feet in height. Within the tower and below the tank are several floors, upon which the whole of the sterilizing apparatus is located. The intake-pump and two lift-pumps (the second in case of emergency) stand on the ground-floor, and alongside

are the air-compressors, also duplicated. Here also are the electric meters, switchboard, the transformer, and two groups of ozonizers. The remaining sets of ozonizers are on the floor above. Higher up still are the sterilizers.

Ozonizers.—The electrical supply is branched from the installation which distributes power to Breda and its environs.

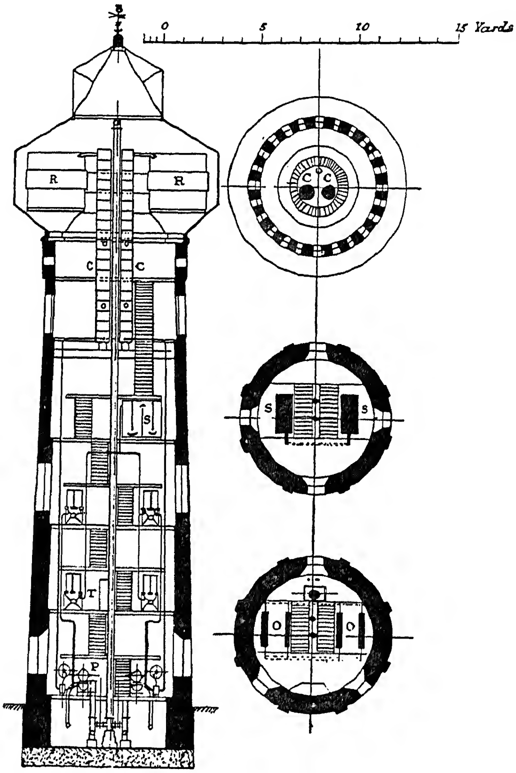


FIG. 61.—STERILIZING TOWER AT GINNEKIN, HOLLAND.

C,C, conduits; P,P, first floor, pumps; O,O, second floor, ozonizers; T, transformer; S,S, third floor, sterilizers; R,R, top story, water tank.

For the production of ozone, the current is transformed from a pressure of 100 to 65,000 volts. On its way to the primary circuit of the transformer, the low-tension current passes through a self-induction coil with laminar core. By withdrawing or inserting the core it becomes possible to regulate

the current traversing the primary of the transformer with great nicety, and by a simple device the core is under control from the floors above.

There are twelve ozonizers, and the number put into circuit is dependent on the degree of contamination of the water. The construction of the ozonizers bears a resemblance to that of the De Frise type described on p. 211, except that the saw-edged discs are replaced by an electrode of the same shape as the outer trough, but of less radius. By means of tubes filled with dilute glycerine the insulated pole of the transformer is joined up to the inner electrodes of the ozonizer, and by adding to or taking from the number of tubes in circuit the current may be varied at will.

Air is sucked into the confined region of high potential after parting with its moisture to quicklime in a special desiccating chamber. With a sufficiency of ozone it is thereafter injected into the sterilizers in such manner that it travels in the contrary direction to the water.

Sterilizers.—The sterilizers are of similar construction to those used in the De Frise system—enamelled cylinders with celluloid sieves, here resting upon perforated grids. The ozonized air rises through the descending water, and is broken up into minute bubbles at the perforations. These bubbles gather into cushions beneath the grids, and so scrub the fine jets of water, which are pressed down, while at the same time the air, squeezing its way upwards, carries on the same work. Owing to the increase of pressure in the cylinders there is increased solubility of the gases, and the good effect of this should be most appreciable in the region of highest pressure—*i.e.*, just where the air and water meet first. At Ginnekin the water must travel through two cylinders in succession. The "equation" between the oxidizable matters and the ozone is so adjusted that 94 per cent. of the ozone introduced is absorbed in the first cylinder traversed, and 61 per cent. of that injected direct from the ozonizer into the second sterilizing cylinder is used up. There is thus not a great superfluity of the purifying gas after the first reaction, but the excess from the final stage would enrich the air going towards the ozonizer. It does not appear that provision was made for recovering the unabsorbed ozone—at least, not when the plant was first laid down.

Purification Results.—Of the efficiency of the sterilizing work done at Ginnekin there can be no doubt. As absolute safety depends so much upon the species of the survivors from the host of germs, it is only necessary to mention that *B. coli* disappears entirely, and *a fortiori* the less resisting types, as *B. typhosus*, the bacillus of cholera, must, if present, have perished. The survivors are few, and are mostly *B. subtilis*, moulds, and harmless types.

The chemical analysis proves that there is a considerable betterment as regards organic content. The oxygen consumed is reduced about one-half, and the ammonia diminishes. The following is a sample analysis :

TABLE XIII.

	Parts per Million.	
	Before Treatment.	After Treatment.
Oxygen consumed	31·00	17·00
Ammonia	0·20	0·03
Albuminoid ammonia	0·23	0·20
Solid residue on evaporation ..	174·00	170·00
Combustible residue	52·00	44·00
Chlorine	16·50	16·20
Ferric oxide	1·50	0·30

Working Costs.—Turning now to the cost of this process, it must be borne in mind that the installation is a small one, only 100,000 gallons passing through in twenty-four hours. The economies effected in large plants cannot be looked for here. The power required varies with the condition of the raw water, 1 m^3. at the most favourable time demanding an expenditure of 250 watts, and of double that quantity when things are at their worst. The average cost for electrical energy is 44s. per 1,000,000 gallons. Manual labour costs £96 annually, and interest on capital £125. The daily run is rather more than 100,000 gallons, but, making allowance for the economy of a larger undertaking, we may reckon that the total expenditure under the last two heads should not exceed 40s. per 1,000,000 gallons.

The capital outlay on the roughing-filters, pumps, switchboard, transformer, ozonizers, and sterilizer, amounts to £800.

The settling basins and fine-sand filters cost £600. The current generators at the local power-station may be estimated at £200.

A comparison of these figures with those given on p. 225 for the Lahmeyer system will show that small installations are costly. The working expenses are high, far beyond those estimated for the new installation at St. Maur, where the daily output may be as much as 20,000,000 gallons.

The Howard-Bridge Ozonizer.—Considerable economies are effected by the apparatus illustrated in Fig. 62. In the

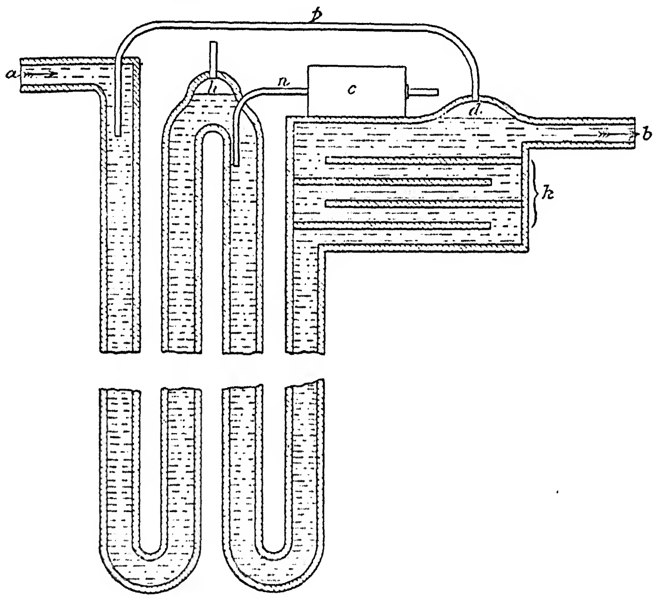


Fig. 62.—The Howard-Bridge Ozonizer.

first place, the unused ozone is gathered up in the chamber *d*, and led back into the incoming water by way of the pipe *p*. In travelling through the U-tube along with the crude water, it is practically all utilized, and the air with which it was mixed is allowed to escape at the outlet *h*. Freshly ozonized air is then introduced from the ozonizer seen at *c*, and this accompanies the current along a second U-tube, and finally round a series of baffle-plates, *k*.

This arrangement is found to be quite satisfactory as regards

sterilization. A series of tests proved that on the average the bacterial content is diminished from 80,000 per c.c. to 8, and that none of the survivors are harmful.

A second important advantage of the Howard-Bridge system is that no power is required for compressing the ozonized air into a sterilizing chamber, or, in fact, for keeping up the circulation of the air operated upon. The suction of the descending water is sufficient. Besides, the compression of ozonized air is attended with certain difficulties, because the ozone attacks lubricants, and the piston must be left to ply without them. Hence it has to fit tightly into the cylinder, and there is increased friction and wear.

The cost of sterilization by this process is about 70s. per 1,000,000 gallons, allowing 1·3 grammes of ozone per m^3. The plant in which the Howard-Bridge ozonizer operates deals with 1,500,000 gallons daily. Dr. Erlwein estimates that with an output six times greater the costs would be reduced to 30s. per 1,000,000 gallons.

Sterilization by Ultra-Violet Light.—It is a well-established fact that ultra-violet rays are strongly bactericidal, and M. Victor Henri has shown how the sterilization of water may be carried out on a large scale by subjecting the crude water to the radiation from a Cooper-Hewitt mercury-vapour lamp. The lamp is placed in the bend of a semicircular trough, through which the water is led, and is supplied with a current of 3 amperes at a pressure of 220 volts. The apparatus has been tested at Marseilles, where it operated for six weeks continuously; *B. coli* were always present, though not in large numbers, and these were entirely destroyed. Other germs occurred to the extent of 30 to 300 per cm^3. in the raw water, while the filtrate only showed 1 per cm^3. on the average.

The daily output was 130,000 gallons, with an expenditure of 120 watts per thousand gallons. Hence this system of sterilization is a very economical one, and if it be shown to deal with other supplies as effectively as it has done at Marseilles, it is likely to attract much attention in the future. (See further, Chapter XIV.)

CHAPTER IX

WATER-SOFTENING AND HOUSEHOLD APPLIANCES

House Filters

In regard to household filters, it is of the first importance that the consumer should understand that the efficiency of any filtering medium, such as charcoal, spongy iron, unglazed porcelain, has a time limit depending on the quantity of water passing through, and the amount of polluting matters to be intercepted. Periodical cleaning is imperative, for the filtering substance soon becomes loaded with débris, and forms a seed-bed for the growth of micro-organisms. The thickness of the intercepting layer being small, these soon find their way through, so that the filtered water may become richer in bacteria than the supply.

Charcoal Filters are apt to become clogged with slime rich in bacteria, and the oxidizing action of this medium is thereby counteracted. At the Medical Congress held in Berlin in 1886. a large number of household filters were examined, and most were found to be useless, bacteriologically speaking. Clay and asbestos packing appeared to be proof for a few days, while charcoal and spongy iron often failed to retain bacteria from the first. There is a difficulty in manipulating the asbestos filter, but the Chamberland-Pasteur porcelain apparatus is effective and fairly simple to manage. A good head of water is required for even a moderate delivery of filtrate in the latter case. Drs. Woodhead and Cartwright Wood found that without pressure the Chamberland-Pasteur filter required seven hours to pass 1 pint of water. The Berkefeld filter is nearly as efficient as the Pasteur, and it is more rapid in its action. With a pressure of $1\frac{1}{2}$ atmospheres ($22\frac{1}{2}$ pounds per

square inch, or 50 feet of head), the Berkefeld filter yields 2 pints in one minute.

Other satisfactory household filters, so far as concerns the retention of micro-organisms, are the Puckall, Duff's Patent, Porcelain d'Amiante, and Slack and Brownlow's.

The **Berkefeld Filter** is represented in the annexed diagram, Fig. 63. It consists of an iron cylindrical case, enamelled internally, and containing a hollow candle of compressed

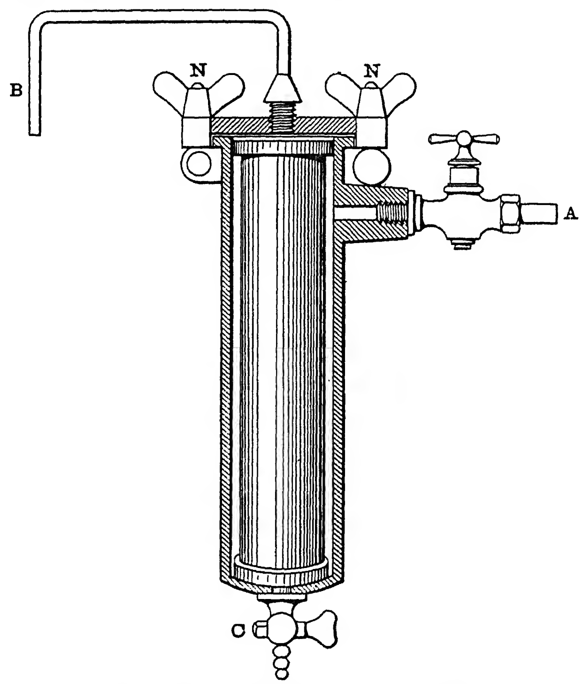


FIG. 63.—THE BERKEFELD FILTER.

kieselguhr, which is the effective part of the apparatus. The water enters at A, filling the annular space between the case and the kieselguhr core. It permeates the filtering material, and trickles into the central bore, from which it escapes by the outlet B. There is a scour-pipe below at C. By unscrewing the nuts at N, the core can be removed and cleaned. This is best done by scrubbing, and placing in boiling water to bring about sterilization. It has been recommended to fill the annular space after cleaning with water in which a little

powdered diatomaceous earth has been suspended. This powder gradually becomes encrusted upon the filtering surface, and most of the slime adheres to it. At the next cleaning the superficial crust is easily scrubbed off. It may even be removed by forcing air into the core—as, for example, by attaching a cycle pump to the efflux-tube B, and pressing air into the bore while the candle is held under water. This procedure tends to clear out the pores, while the superficial layer of diatomaceous matter hinders clogging, and so the output of the filter is kept steady for a long time.

A Berkefeld filter with one candle will yield 20 to 30 gallons per day, with a pressure of 35 to 40 lbs. per square inch ; but if a greater output is demanded, a filter with two, three, or more candles packed in the same case is supplied.

It is usual to have a small holder for the filtered water, so that the process of purification may go on continuously with the inlet tap turned on. The holder should be kept covered, and an overflow pipe affixed. The filtered water is drawn off by a tap below.

When the requirements of the household only amount to a few gallons daily, the **porcelain filters** (d'Amiante or Chamberland) will answer the purpose with the aid of a holder. Many authorities consider this type of filter to be the most reliable for the retention of bacteria. Porcelain filters, like other varieties, require periodical cleaning, and, through clogging, the output falls off from day to day.

House filters in which the water is sterilized by **ozone** are coming into general favour. That supplied by the Compagnie Générale de l'Ozone is a very effective bactericide. The general construction will be understood by reference to Fig. 64. The initial cost may be somewhat high, but, once installed in a situation where current can be taken from the electric mains, the expense of working is trifling ; the output is equal to that of the free tap, and the water is wholesome and well aerated. No taste arising from the sterilizing gas is observable after a minute or two. A thoroughly reliable house ozonizer may be bought for about £8.

Where a supply of current is not available, and when it is desired to sterilize completely, an alternative is to boil the water. There are several devices for accomplishing this without using any cumbrous appliances.

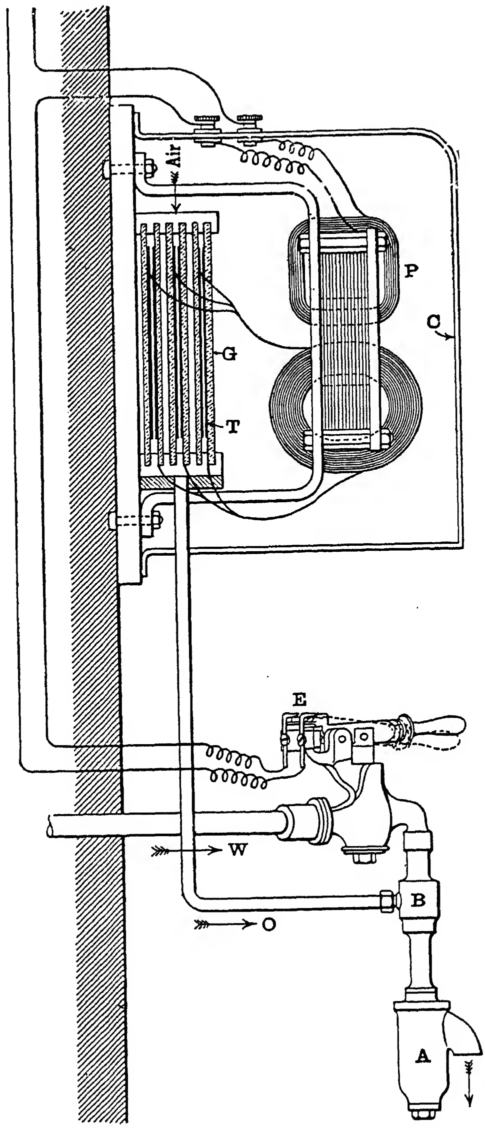


FIG. 64.—OZONIZING FILTER FOR HOUSEHOLD USE.

A, outlet; B, inlet of ozonized air; W, crude water; G, glass; T, tinfoil; P, transformer; C, cover of ozonizer; E, switch and tap.

The Forbes Patent Water Sterilizer.—This apparatus, which is represented in Fig. 65, has been adopted in the United States army, where several thousands are in daily use. A feature of the patent is that the water is just brought to the point of ebullition, and then immediately cooled, so that it issues from the sterilizer at a temperature not many degrees above that at which it entered. Within the body of the apparatus the raw water is made to ascend in a number of parallel columns, indicated in the section by dark lines. These parallel conduits are confined by thin metallic walls, and between them descends the warm water that has left the boiler. A ready interchange of heat takes place, so that the raw water arrives at the boiler quite hot, while the sterilized water has parted with much of its heat by the time that it has sunk to the bottom, where it finds an outlet.

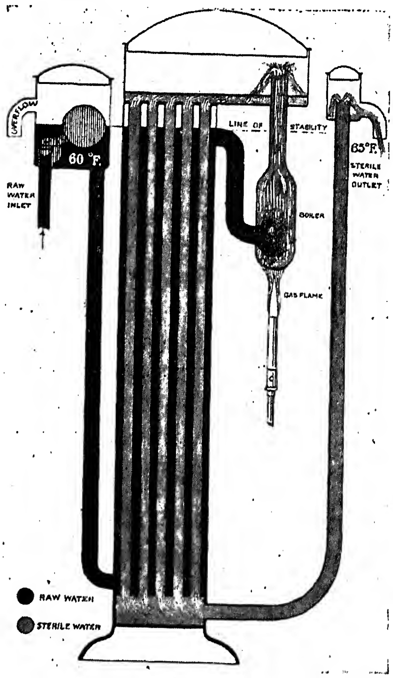


FIG. 65.—THE FORBES PATENT WATER STERILIZER.

The raw water as it rises in temperature tends to lose aeration, but owing to the construction of the sterilizer the oxygen and carbonic acid expelled by the heating are carried along in the stream, and are reabsorbed as the temperature falls. For this reason the water which flows from the outlet is found to be so well aerated that it has none of the flatness and insipidity of water which has been boiled in an open vessel. That a satisfactory aeration remains has been proved by experiments carried out by the military authorities in the United States.

The arrangement in parallel columns of incoming and outgoing streams has the double advantage of economizing heat

and of cooling the effluent. The cost of sterilizing 100 gallons with gas or petrol as fuel is not more than 2d., while if exhaust steam is available the expense would be about ¼d. The sterilizer will work continuously for years, and cleaning is not required. Muddy water should be subjected to rough filtration before being introduced.

A small Forbes sterilizer capable of dealing with 3 gallons per hour, built of rolled copper and brass, tin-lined, can be had for £7 10s. Larger units, to deal with 10, 25, etc., up to 15,000 gallons per hour, are supplied.

WATER-SOFTENING AND ITS APPLIANCES.

The dissolved substances which principally give rise to "hardness" are the carbonates of lime and magnesia, and their sulphates. Occasionally we find chloride of magnesium and iron carbonate. All these substances may be removed by appropriate methods of water-softening. Salts of soda, potash, and ammonia, are often present in potable waters; but no attempt is made to remove these, for the operation would be expensive, and in moderate quantities they do not affect the water either from a hygienic or an industrial point of view. Distillation would separate all solids, but this is only made use of in the last resort, when nothing better than brackish water or sea water is available.

For the understanding of the theory of water-softening merely a simple acquaintance with a few chemical reactions is necessary. It has long been known that hard waters are softened to a great extent by boiling. Water from the chalk leaves a deposit in kitchen boilers, and the hot water is often quite milky. Boiling, however, does not remove all the hardness. When hard water is used to feed steam-boilers, there occurs a further deposit of mineral matter, which joins with the first precipitate in forming an incrustation or *scale* on the walls.

Temporary and Permanent Hardness.—Again, if hard water be shaken up with a soap solution of definite strength and in measured quantity, a certain amount of the solution must be applied before a lather will form. Let this amount be called M. If now an equal volume of the same water be boiled for a few minutes, cooled, and again treated with the soap solution,

it will in general be found that a certain volume must be added before the lather forms, and that this volume will be less than is required for the unboiled water. Call the latter N. Then M is a measure of the total hardness, and M—N measures the amount of hardness that has been destroyed by boiling. This is called *temporary* hardness. There remains that portion of the soap-curdling minerals which boiling does not throw out of solution. This part, which we have denoted by N, is the *permanent* hardness. Temporary hardness is caused by the presence of bicarbonates of lime and magnesia. To these may be added the bicarbonate of iron. The removal of that substance is often effected by special devices elsewhere referred to (p. 333). When water containing these bicarbonates is boiled, there ensues a loss of free carbonic acid dissolved in the water, and also of the carbonic acid associated with the bicarbonates. The result of the latter effect is that the bicarbonates are converted into carbonates. That is to say, using the chemical notation in which CaO stands for calcium oxide or lime, CO_2 for carbonic acid, and H_2O for water, the compound $CaOCO_2 + H_2OCO_2$ becomes changed to $CaOCO_2$ through the separation of water and carbonic acid. An exactly similar decomposition takes place with the bicarbonates of magnesia and iron. Simple carbonates are thus produced, which are nearly insoluble except in the case of magnesia, the carbonate of which is slightly soluble (7 grains per gallon, according to Chevalet; see also Comey on Solubilities, p. 87).

Removal of Temporary Hardness.—Thus the abstraction of carbonic acid removes almost all the substances which give rise to temporary hardness. As it would be impracticable to boil large volumes of service water, a chemical process is employed to bring about the same result. If either lime-water or milk of lime be added, the carbonic acid, both free and in combination to form bicarbonate, is absorbed by the lime, leaving only simple carbonates which precipitate as before. This reaction is expressed by the following chemical equation :

$$\text{Bicarbonate of lime} + \text{lime} = \text{carbonate of lime} + \text{water.}$$
$$\underset{\text{(soluble)}}{CaOCO_2 + (H_2OCO_2)} + CaO = \underset{\text{(insoluble)}}{2CaCO_3} + H_2O$$

The simple carbonate of lime, $CaOCO_2$ or $CaCO_3$, as it is usually written—is thereby eliminated. Exactly the same

reaction follows in the case of bicarbonate of magnesia, but the precipitation of the carbonate is not complete. However, by introducing a sufficiency of lime-water the simple carbonate of magnesia is further acted upon, and is converted into the hydrate of that base, $Mg(OH)_2$, which is insoluble, and so the magnesia salts are also removed. The chemical changes are thus represented :

Carbonate of magnesia + lime + water = hydrate of magnesia + carbonate of lime.

$$\underset{\text{(slightly soluble)}}{MgOCO_2} + CaO + H_2O = \underset{\text{(insoluble)}}{Mg(OH)_2} + \underset{\text{(insoluble)}}{CaCO_3}.$$

Thus the temporary hardness is remedied in a way which involves no great expense, and but little trouble in its application. The proper quantity of lime to add is determined by an analysis of the hard water. It then remains to devise a method of introducing lime-water or milk of lime automatically in the required proportion.

Removal of Permanent Hardness.—Permanent hardness—hardness irremovable by boiling—is due to the presence of various salts, but in general those which it is desirable to remove are the sulphates of lime and magnesia (and very rarely the chlorides). It is these salts which help to form incrustations on boiler plates, and which also decompose soap, and hinder the formation of a lather, just as the carbonates of the same bases do. They dissolve in water without the aid of carbonic acid, and are not affected by boiling. The method of dealing with them consists in adding a chemical which has the power of changing them into carbonates—in other words, which is able to transpose the permanent into temporary hardness. Calcium and magnesium sulphate sand chlorides (if present) are changed to carbonates. In this condition they are removed as already explained.

To convert sulphate of lime into the carbonate, we add carbonate of soda. The chemical reaction which follows is thus expressed :

Sulphate of lime + carbonate of soda = carbonate of lime + sulphate of soda.

$$\underset{\text{(soluble)}}{CaSO_4} + Na_2CO_3 = \underset{\text{(insoluble)}}{CaCo_3} + \underset{\text{(soluble)}}{Na_2SO_4}$$

The carbonate of lime falls out, and there is left a corresponding amount of sulphate of soda; but this is harmless, neither causing scale nor hindering the formation of a lather.

The reaction with sulphate of magnesia is similar. If there be sufficient carbonic acid dissolved in the water, caustic soda may be employed, for this absorbs the carbonic acid and becomes carbonate of soda, and reacts as stated. In practice it has been found that there is difficulty in treating with caustic soda unless the matter is in the hands of a good chemist, because it is not desirable to leave any appreciable residue of soda in the water. Hence the quantities must be accurately gauged. This is of less importance when carbonate of soda is employed.

For dietetic purposes a moderately hard water is preferable to a soft water, but very hard waters cause derangements of the system, and are said to produce calculi, goitre, etc. Medical men are not altogether in agreement on the latter point. As the result of an official inquiry in France, it was made out that the physique of people using hard waters was distinctly better than that of those who were supplied with soft water.

Effect of Hard Waters on Soap.—It is not from a hygienic point of view that water-softening is in general demanded. It is rather for economical and industrial advantages accruing that the treatment deserves attention. The loss entailed by the use of hard water to dissolve soap is very considerable. As fast as the soap dissolves it is broken up by the lime and magnesia salts, with the formation of insoluble stearate of lime, which floats on the top, and is valueless for cleansing purposes. At the same time a corresponding amount of sulphate and carbonate of soda is formed. The chemical reaction may be thus represented :

$$\underbrace{(\text{Stearic acid} + \text{soda})}_{\text{(soap)}} + \text{sulphate of lime} = \underbrace{(\text{stearic acid} + \text{lime})}_{\text{(stearate of lime)}} + \text{sulphate of soda.}$$

With the carbonate of lime (chalk) there is the same reaction, except that carbonate of soda results. As 1 part of carbonate of lime decomposes 6 parts of stearate of soda, and as commercial soap contains only 60 to 70 per cent. by weight of stearate of soda, it follows that 1 pound of dissolved chalk will destroy 9 pounds of soap. One hundred gallons of water containing 20 grains of chalk per gallon will destroy $2\frac{1}{2}$ pounds of soap before any lather is formed. Water containing 20 grains of sulphate of lime per gallon is similarly able to decompose about 20 pounds of soap for every 1,000 gallons used. Thames

water is said to decompose about 15 pounds of soap per 1,000 gallons, entailing a loss of 4s. or 5s.* As the cost of softening this quantity would not exceed 2d. (including materials and labour), the economical advantage of water-softening is self-evident.

Scale in Boilers.—In boilers hard water is a source of much trouble. The crust or scale which forms on the walls is a poor conductor of heat, and in consequence the boiler plates become overheated, and are liable to suffer from excessive strains. There is a greater consumption of coal with a foul boiler, and the removal of scale is a costly operation. It is not enough to remove the temporary hardness only, for at high temperatures sulphate of lime crystallizes out pretty freely, especially when, as a result of concentration during the steaming, the water has become highly charged with this compound. At the temperature of boiling water about 150 grains of calcium sulphate will dissolve per gallon, but at a temperature of 356° F. (148 pounds per square inch) less than 20 grains dissolve per gallon. For boiler feed both temporary and permanent hardness require removal.

Measure of Hardness ; Amount of Lime and Soda required for Softening.—It is customary to indicate hardness by so many degrees, in accordance with Clark's soap test. One degree of hardness means 1 grain per gallon, 10 degrees 10 grains, and so on. One British degree of hardness corresponds to 1·4 degrees on the French scale, and 0·81 on the German.

To soften 1,000 gallons of 10 (British) degrees of temporary hardness, 0·8 pound of caustic lime is required. If caustic soda be employed for this purpose, rather more than a pound of 78 per cent. strength would be necessary, but the soda is much more expensive. Hence it is brought into use in general only when it is indispensable—that is, for the removal of permanent hardness. One pound of soda of the same strength as above would dispose of 10 degrees of permanent hardness in 1,000 gallons. If soda ash of 56 per cent. strength be used, $1\frac{1}{2}$ pounds would be required. Referring to the chemical equation on p. 238, it will be seen that carbonate of soda is the substance which decomposes the sulphates of lime and magnesia. As already remarked, caustic soda may be taken instead if

* Proc. Assoc. of Engineers in Charge, vol. x., No. 4.

there be sufficient free carbonic in the water to convert it into the carbonate. This is a matter for the chemist to determine. Soda ash is made use of in very many water-softening appliances.

Cost of Chemicals.—The cost of lime sufficient for 1,000 gallons of 10 degrees temporary hardness may be $\frac{1}{10}$d., while the soda ash required to remove 10 degrees of permanent hardness would be nearly 1d. for the same volume of water. The cost varies with the amount of hardness and with the nature of the salts present. More lime is required if magnesium carbonate is present. For example, it is calculated that, to soften a water containing 13 grains of calcium carbonate per gallon and 2 parts of magnesium sulphate, about $\frac{1}{2}$d. per 1,000 gallons would cover the cost of chemicals. But with 13 grains of calcium carbonate and 14 grains of magnesium sulphate the cost would be three times as much. Very hard waters of from 70 to 100 degrees may be softened at a cost (for materials alone) of 1d. per 1,000 gallons, if the hardness is nearly all of the temporary kind, but if half of it be permanent the cost would be two or three times as great.

Method of applying the Treatment.—The artificial softening of water for distribution is usually restricted to the removal of the greater part of the temporary hardness, there being no objection from the point of view of health to moderate amounts of sulphates of lime or magnesia. There are numerous mechanical appliances for introducing chemicals automatically, some of which will be described later. But where the aim is to remove a part of the temporary hardness, no great accuracy or uniformity in the results being looked for, it is customary to adopt the simple expedient of adding by hand a measured weight of lime to the contents of a settling basin, allowing time for precipitation, and then filtering through cloth screens. An approach to automatic regulation is made by placing the lime in hoppers, bringing in water from below through a regulating tap, and then conducting the liquid, which may be milk of lime or simply lime-water, into the inflow to the settling basin. As milk of lime, containing 10 per cent. of lime, is about eighty times stronger than lime-water, it is often preferable to use the lime in that form. Some device must then be installed to stir up the lime and water continuously. This may consist of a

wheel with stirring blades driven from the incoming stream of water. At the Bradford Corporation Waterworks an apparatus of this kind was introduced for the purpose of *hardening* a soft water with ground chalk, and good results followed.

Automatic Devices for introducing the Charge of Chemicals.—Various devices are in use for the purpose of delivering measured quantities of the chemicals when the water has to be prepared for boiler feed. In the Lassen and Hjort apparatus the successive tilting of a trough filled by the inflow admits milk of lime through a valve. To insure that the valve will always admit the same amount, it is necessary to keep the same head in the mixing tank, and arrangements must be made to insure this. In the Doulton apparatus milk of lime is admitted by a ball-cock operated from the mixing tank. In some cases the lime-milk is delivered by a pump driven from the inflow or from a separate motor. When lime-water is employed, it is important to provide for a strong and nearly saturated solution. Lime dissolves slowly, and at best forms a weak solution of about 90 grains per gallon. Hence the arrangement must allow of the water and lime remaining in contact for a sufficient time with continual stirring. In the Harris-Anderson plant a current of air is forced into the mixture to keep it in agitation.

Once the lime-water has been properly made, there is less trouble in regulating the dose. A good system is the Desrumeaux (p. 250). Several makers have introduced pumps with success. The main difficulty, as already stated, is to prepare a solution of good uniform strength, and for this care should be bestowed on the dissolving tank.

The same considerations apply to the application of a soda solution. The utmost importance attaches to the preparation of the solution. Whether it is prepared in the cold or with the aid of exhaust steam, it is very desirable that it should be of known strength, and uniform during the period of its application. It is perhaps fortunate that some excess of soda does not seem to be very harmful to boiler connections. Some of the devices for regulating the introduction of the soda solution are illustrated later.

Removal of the Precipitate.—The precipitation of the salts which contribute to hardness having been assured, there remains the untoward circumstance that the sludge settles

very slowly. According to Professor Wanklyn, it takes twenty-five minutes for the precipitate to settle down completely from the top layer, ¾ inch deep. The Archbutt-Deely process of stirring up the old precipitates to commingle with the new appears to accelerate greatly the rate of sedimentation. Heating also is of much assistance, but this method is applicable to small supplies only. In the cold the rate of sedimentation does not exceed 2½ inches per hour. Hence arises the necessity for filtration through cloth screens, wood fibre, or sand. Magnesium carbonate and hydrate, if forming any considerable part of the precipitate, occasion much trouble, both because they settle more slowly and because they are more apt to clog the filters.

In connection with water-softening plants, it is sometimes noted that unsatisfactory working results from the use of too little lime. It should be remembered that in general the lime has three distinct reactions to complete. First, it must absorb the free carbonic acid, and, as water can dissolve its own volume of this gas, a considerable part of the lime in the lime-water might be used up for this purpose alone. Secondly, the lime has to combine with the half-bound carbonic acid of the bicarbonates of lime and magnesia. And, lastly, it may be required to transform the magnesium carbonate into the insoluble hydrate.

We now proceed to describe some of the more typical water-softening plants.

Paterson's Cold Process of water-softening is a convenient apparatus which is nearly automatic in its operation. The chemicals employed are lime in saturated solution, and carbonate of soda. There is provided a measuring weir controlled by a float which regulates the position of a pair of conical valves. One of these admits the soda solution; the other controls the flow of water to the lime saturator. The arrangement will be understood from the annexed figure (Fig. 66). Each day the necessary weight of the chemicals is placed in the receptacles. The solutions commingle with the incoming water, and this passes on to a settling tank, and enters by a pipe well below the surface. The water thus treated rises to the overflow, passing first through a screen of wood fibre. From the conical base of the tank the precipitated impurities can be readily sludged

off. By altering the set of the conical valves the supply of the chemical reagents can be adjusted to deal with any ascertained degree of hardness. It is contended, probably with

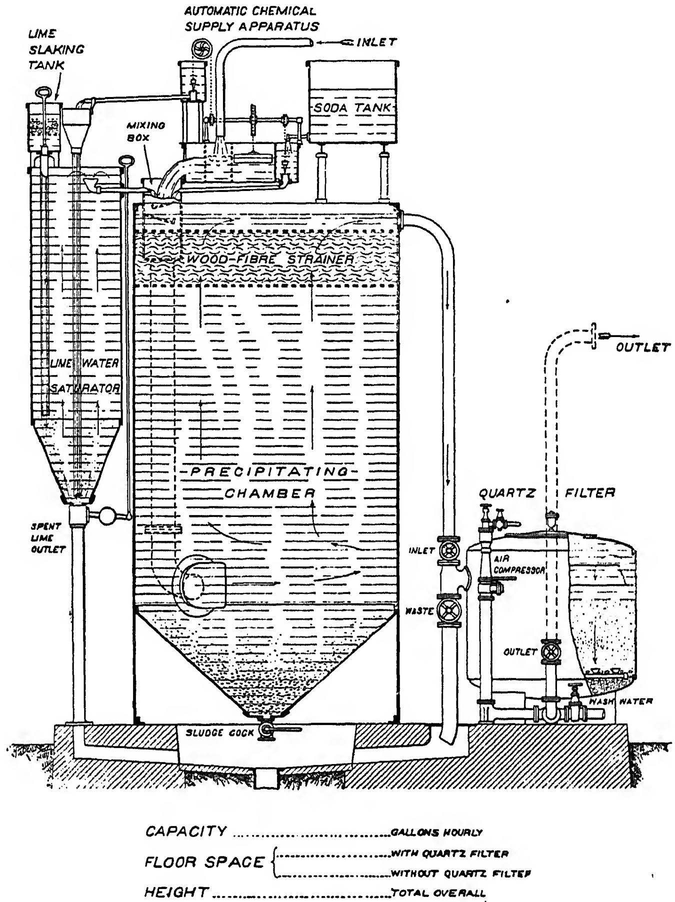


FIG. 66.—PATERSON'S WATER-SOFTENER WITH QUARTZ FILTER.

reason, that a saturated solution of lime is better than milk of lime, which is of variable strength and less easily regulated.

In **Paterson's Steam Purifier** the arrangement is adapted to bring the water into full contact with the spent steam. Heating

powerfully aids the removal of temporary hardness, so that there is a saving of lime. Hence only soda requires to be added. To insure perfect exposure of the water to the steam, it is caused to fall from one tray to another in fine streams. Below is a sedimentation chamber, where the precipitate is collected and drawn off at intervals. The exhaust steam is deprived of oily matters by being passed through a grease separator before it is applied to the water. The economy of

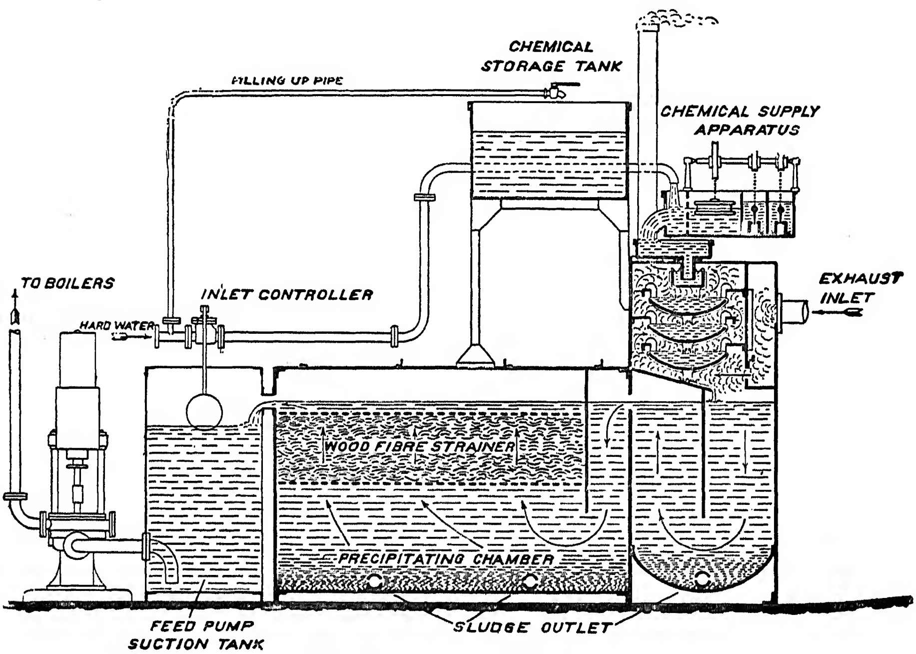


FIG. 67.—PATERSON'S STEAM PURIFIER.

utilizing exhaust steam to raise the temperature of boiler-feed water is apparent, and may amount to 10 per cent. of the coal bill (Fig. 67).

Lassen and Hjort Water-Softener.—There are several interesting features in this apparatus, and its serviceableness has been proved by efficient work at numerous stations. The reagent employed is in general milk of lime containing 10 per cent. of lime, together with the requisite amount of soda ash or caustic soda. Lime-milk is many times more powerful

than a solution of lime, and the construction of the softener is such that the dose can be regulated and applied without difficulty. In the illustration (Fig. 68), the hard water arriving by the pipe K descends into a pivoted double **V**-shaped re-

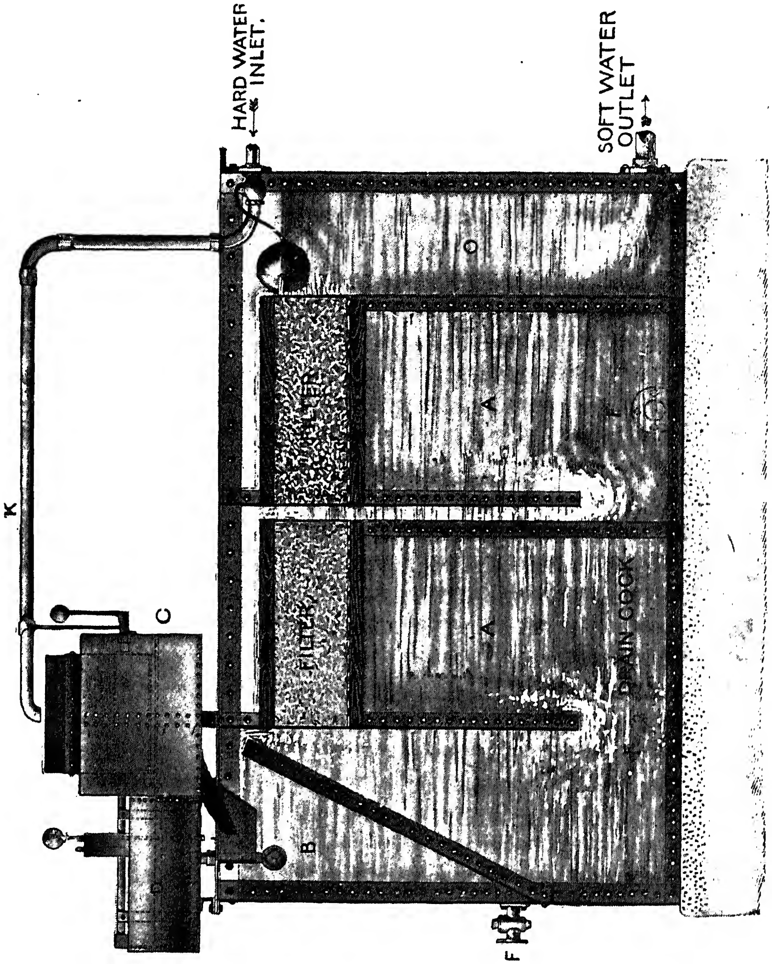


FIG. 68.—LASSEN AND HJORT'S WATER-SOFTENER.

ceiver, C, which tips as soon as the water has filled a compartment to a certain depth, and sends its contents into the mixing chamber B. The half-turn then brings the other compartment of the receiver under the outflow from K. Alongside of the tipper is a cistern, D, containing the milk of lime (Fig. 68).

When the receiver turns over, it actuates a valve on the under-side of the cistern, and allows a definite quantity of the milk of lime to fall into B along with the hard water. The milk of lime is agitated by carrying a spindle from the tipper to a fan agitator within the cistern, so that the turning of the former keeps the milk of lime steadily stirred and uniform in strength.

There are regulating screw nuts on the valve spindle for gauging the amount of milk of lime that escapes at each movement, so that different qualities of hard water may be dealt with. A tank for holding the main volume of the milk of lime is placed above the apparatus, or, if it has to be set at a lower level, the liquid is raised to the cistern D by means of a specially-devised pump which can be driven by the flow of the hard water. Into this tank is put the daily charge of burnt lime of the best quality, and the discharge into the feed cistern D is regulated by a ball-cock valve.

In the precipitation chamber B, the carbonates of lime and magnesia separate out and subside. Where this apparatus is employed to soften boiler-feed water, it is an aid to the precipitation to lead exhaust steam into B, so as to keep the temperature up to 150° to 200° F. A denser fall of the precipitate thus ensues, and much less time is necessary.

From the chamber B the water filters upwards through a layer of wood-wool, passing on to a second compartment, where the filtration is repeated. The filtered water collects in the compartment O, which may also be steam-heated. Sludge outlets, F, F, are provided to draw off the precipitate. On the filtered water rides a ball-cock to regulate the inlet of hard water.

The wood-wool is packed between two rows of wooden deals, and in cleaning the upper row is removed and the filtering material lifted. It has been found that cleaning only requires to be done at long intervals, several months being the usual run.

A Lassen and Hjort purifier to deal with 2,000 gallons per hour would cost about £250. The working costs need not exceed 1d. per 1,000 gallons, including allowance for depreciations and outlay for chemicals, lime being reckoned at £1 per ton, and soda ash at £4. The expenditure for chemicals will vary with the nature of the hardness, and will be increased if much alkali is required.

Mather and Platt's Water-Softening Process.—This process, known as the Archbutt-Deeley, is designed to accelerate the precipitation of the carbonates of lime and magnesia after the appropriate reagents have been added. It is found that if the former precipitates, which form a sludge at the bottom of the tanks, be stirred up by a stream of air under pressure from perforated pipes, the water clears much more quickly. Two tanks are required for the operation of softening, so that the output may be continuous. While the treated water is flowing out of one tank, the process of softening is being carried out in the other.

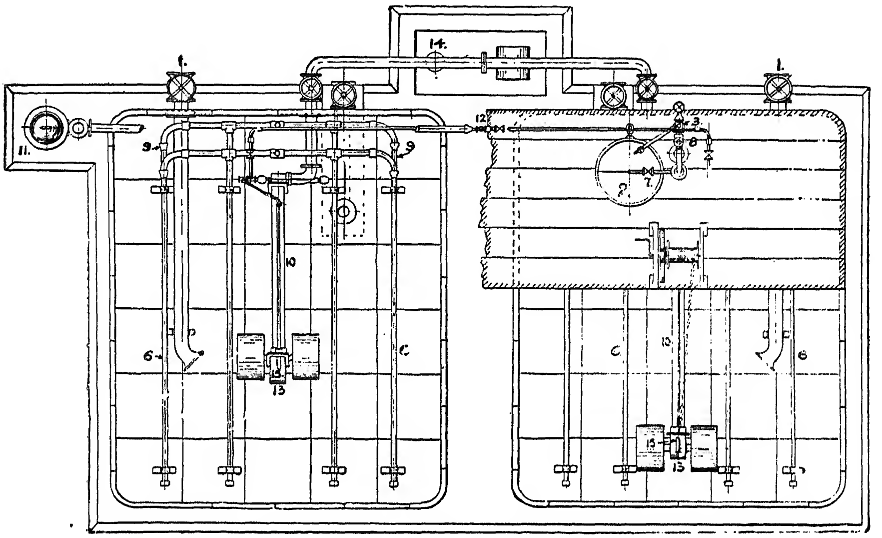


FIG. 69.—ARCHBUTT-DEELEY WATER-SOFTENER (PLAN).
(Messrs. Mather and Platt, Ltd.)

The various steps of the working will be understood from the plan and elevation (Figs. 69 and 70). While the tank is being filled with hard water, the requisite charge of lime and soda is placed in the mixer, 2, and is there boiled up with water and steam. The tank being full, steam is admitted to the blower, 3, so as to set up a circulation beginning at the rose, 4, then to the tap 5, and downwards to the perforated pipes, 6, which lie above and clear of the sludge. Tap 7 is now opened, and the chemicals are drawn into the circulation and distributed throughout the whole volume of water in the tank.

The mixing being completed, the air-tap, 8, is opened, and air is blown through the perforated pipes, 6, so as to clear them of chemicals. This operation needs but a few minutes, and by reversing the three-way tap, 5, the air is next led into

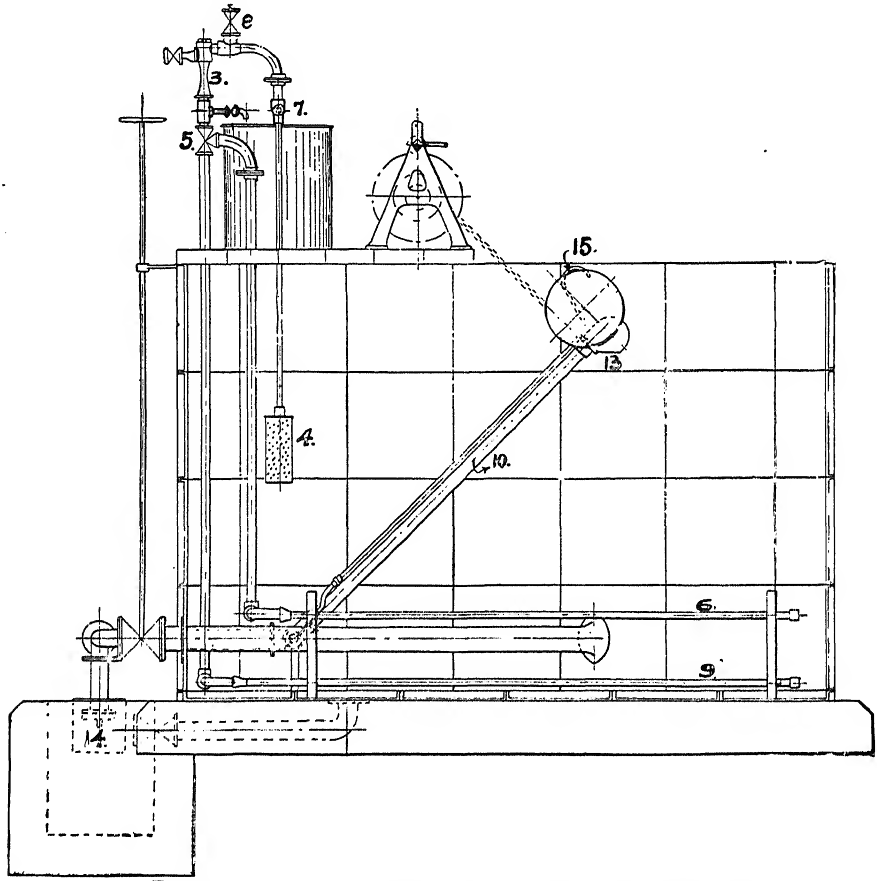


FIG. 70.—ARCHBUTT-DEELEY WATER-SOFTENER (SECTIONAL ELEVATION).

(Messrs. Mather and Platt, Ltd.)

the lower system of perforated tubes, 9, from which it surges up through the older precipitates and drives a cloud of particles through the water above. This action is allowed to go on for a suitable time, according as experience indicates, but ten or twelve minutes usually suffices. The contents of the tank

are now permitted to settle and deposit the precipitate, which is seen to settle down quickly, the heavier particles entraining the finer. After an hour's rest the upper layers are practically free from suspended particles, and it has frequently been found that at a depth of 6 feet not more than 1 grain per gallon remains.

Removal of Traces of the Precipitate.—Small as is the residual precipitate in suspension, it is found advisable to get rid of it in order to prevent its deposition in the outlet pipes when the softened water is to be sent to the feed of a boiler. Mather and Platt's device for this consists in impregnating the outgoing water with carbonic acid gas, which enables the residual precipitate of carbonate of lime to dissolve. How this is effected will be understood by a reference to the diagram (Fig. 70). The water is drawn off through a floating pipe, 10, hinged below, and with mouth dipping under the surface. Carbonic acid gas is prepared in the coke stove, 11, scrubbed if necessary over limestone to remove sulphur compounds, and being actuated by a smaller blower, is led into the outlet pipe, 10, to meet the descending current of water. Unabsorbed gases escape to the air above. The treated water eventually flows away through the ball-tap seen at 14.

At Stockport Corporation Waterworks, where this process has been adopted for softening the service water, there are three tanks, so that while one is being treated the second is left to clarify, and the third is being run off. Twenty-five thousand gallons are passed through the apparatus hourly at a mean cost of 1d. per 1,000 gallons. This figure includes chemicals, wages, sinking fund charges, etc. The hardness is reduced from 13 to 5. Soda is not added, as the permanent hardness is not objected to. For each 1,000 gallons 1½ pounds of lime is made into milk of lime. The initial cost of the Ware softening plant was £4,500. The engineer in charge reports very favourably of the simplicity and reliability of its action (see Report of Brit. Assoc. of Water Engineers, December, 1902).

The Desrumaux Water-Softener.—The Desrumaux system of water-softening has found much favour in France, and it has been proved to work satisfactorily in England. It is an apparatus which needs little attention beyond the charging of

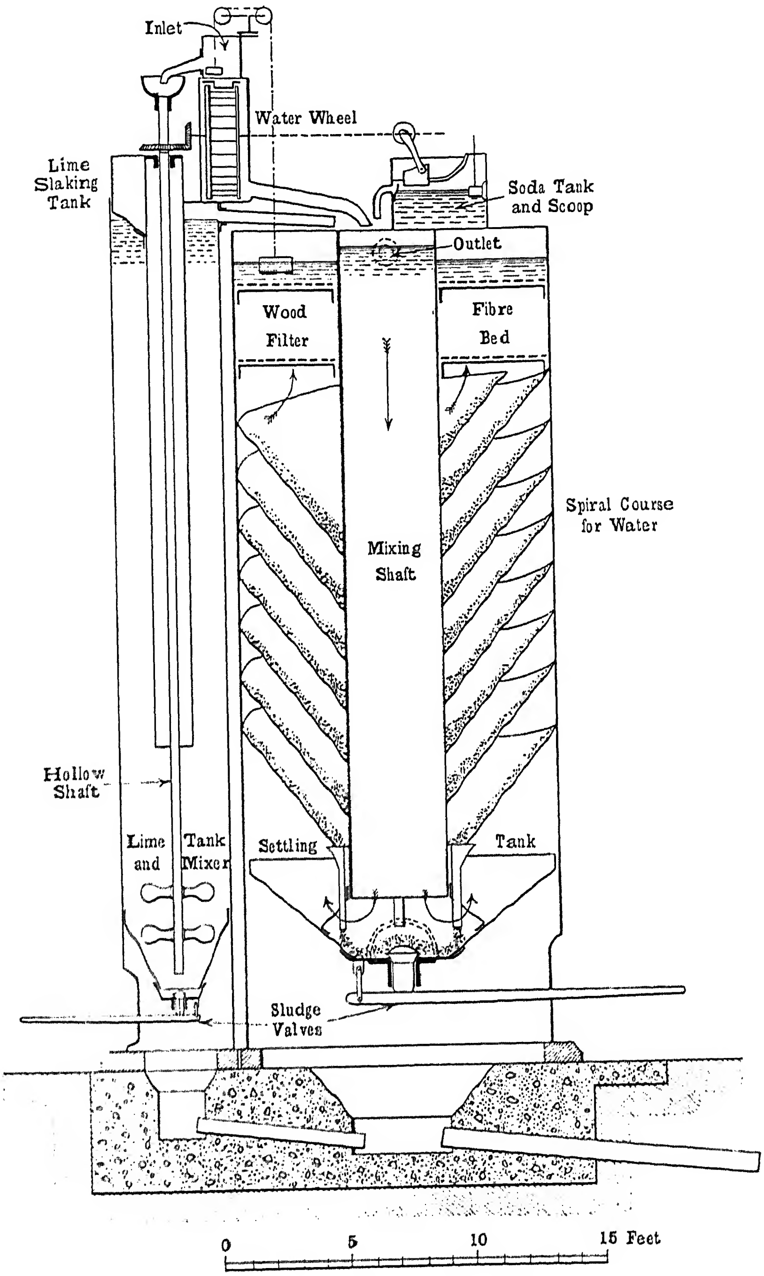


FIG. 71.—DESRUMAUX WATER-SOFTENING APPARATUS.

the mixer with the chemical. The leading feature is a water-wheel driven by the incoming water, which turns a stirrer to keep the liquid in the mixer in motion, and also sets in motion a balanced scoop which throws out the desired volume of soda solution from a reservoir into the general stream. A by-pass leads a part of the main flow into the hollow shaft of the stirrer, so that the water descends to the bottom of the mixer and comes into direct contact with the lime. A solution of lime-water thus formed is allowed to overflow into the central trough of the apparatus. The relation of these parts, and the course of the water and the added chemicals, are illustrated in Fig. 71.

After passing down the mixing shaft, the water ascends through the settling tank. Screw-shaped inclined plates are attached to the circumference of the tank, so that the upward current is directed spirally, and much of the precipitate is left on the plates. Above are filters of wood fibre. A float on the surface of the purified water controls the inflow.

Doulton Water-Softener.—This apparatus (Fig. 72) bears some resemblance to the one just described, and it is in use at many stations. There are two tanks side by side, one for mixing and precipitation, the other for further sedimentation and filtering. They are in communication through an opening near the bottom. The incoming water actuates a wheel which drives two stirrers in the lime and soda reservoirs respectively. The hard water passes into a funnel with a long shank reaching to the bottom of the settling tank, and as the water rises it lifts two ball-cocks and admits the solutions of chemicals to the funnel, so that good mixing is obtained. When the tank is full, the water rises in the funnel and turns the ball-cock valves, which cut off all the inlets. The lime tank is fed with water by a regulating tap, while the soda is generally brought into solution with hot water. In the second sedimentation tank the water rises up to a filter which can be taken out and cleaned.

The Harris-Anderson Softener.—The distributor and solutioner used in the Harris-Anderson purifier (p. 153) may be conveniently used for regulating the dose of soda required for water-softening. Its action is automatic, and no attention beyond putting in the daily charge is necessary. Lime forms

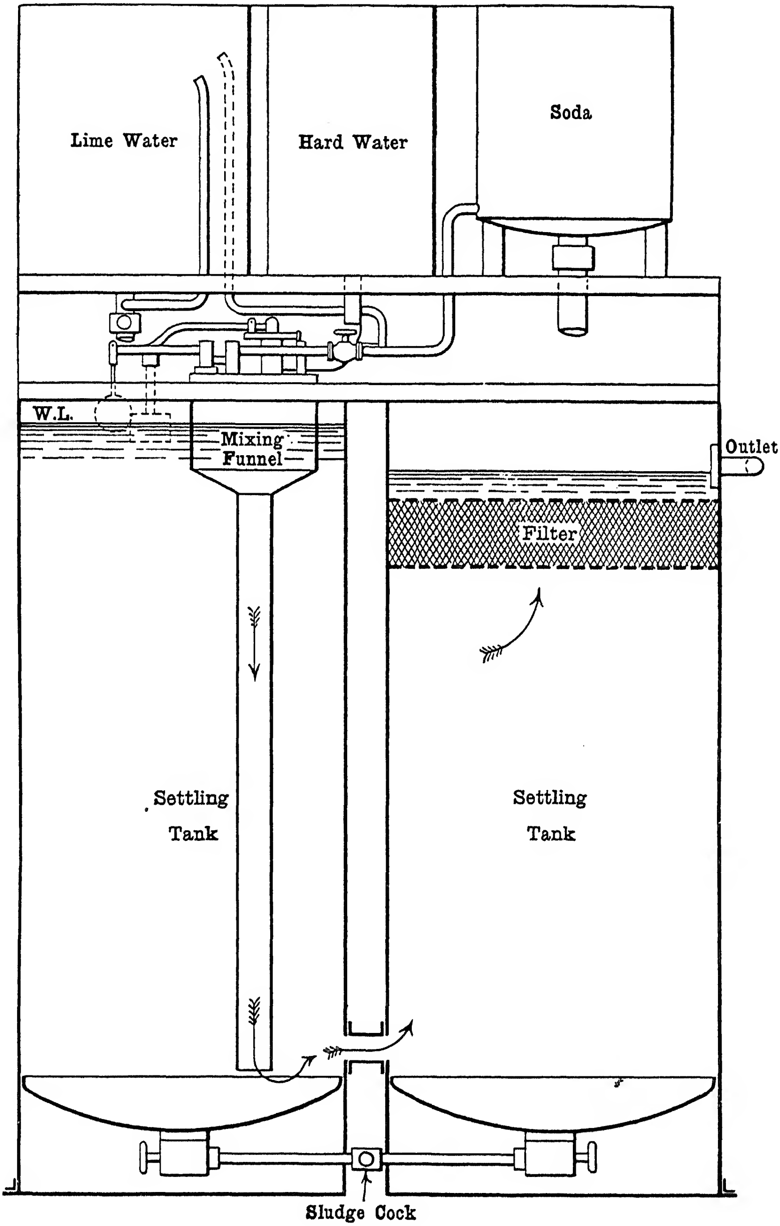


FIG. 72.—DOULTON'S WATER-SOFTENER.

so weak a solution that it cannot be dealt with by the solutioner. Instead, the distributor is adapted to admit any desired fraction of the hard water to a tank containing slaked lime, which is kept in agitation by a blower driven by the incoming water. The overflow is conducted to the mixing chamber along with the hard water and the soda from the solutioner. Thereafter the settling tank is reached, and finally the suspended residue is held by a filter of wood-wool.

In **Bell's Softening Apparatus** the treated water, after sedimentation, is filtered downwards, as in the pressure filter (p. 175), and the sand is washed periodically in the usual manner. There are two chemical tanks, A, and while one is being discharged the other serves for preparing the softening solution. From A the liquid passes to a small reservoir, B, which is kept filled by a ball-cock valve (Fig. 73).

If the raw water is to be elevated to the settling chamber, the main pump is geared to a smaller one, which draws the chemical into the circulation. On the other hand, when there is sufficient head the chemical pump may be driven from a turbine in the supply pipe. Sedimentation of the heavier particles takes place in the chamber F, and from there the upper and clearer fluid overflows into the filters, T, entering through the valves at K. The outlet pipe for the purified water is at L, underneath the level of the drums.

The foregoing may be regarded as types of the water-softeners now on the market. Details of many others will be found in the Proc. of the Inst. of Mech. Engineers, London, for the year 1903. As in the case of adding coagulants, the main difficulty has been to regulate the dose of chemicals to the quality of the water. Most of the softening plants in use have been designed to prepare water for boiler feed, and, naturally, advantage is taken of exhaust steam wherever it is available. This serves to dissolve the soda, to set the water in agitation, to drive blowers, and so forth. But for automatic working it is plainly an advantage to have stirrers and other moving parts driven from the current of hard water.

Whether lime-water or milk of lime is used, there is a difficulty in maintaining constancy of strength. It is hardly possible to make sure that lime-water is saturated, and thus the solution introduced may bring more or less of

the chemical according to circumstances. In selecting an apparatus which softens with lime-water, it is important to note whether the conditions allow a thorough contact of the water and lime, as well as a sufficient time for the solvent action to come into play. Again, if milk of lime be employed, there should be arrangements for continuously stirring the pasty liquid and keeping the milk of uniform density.

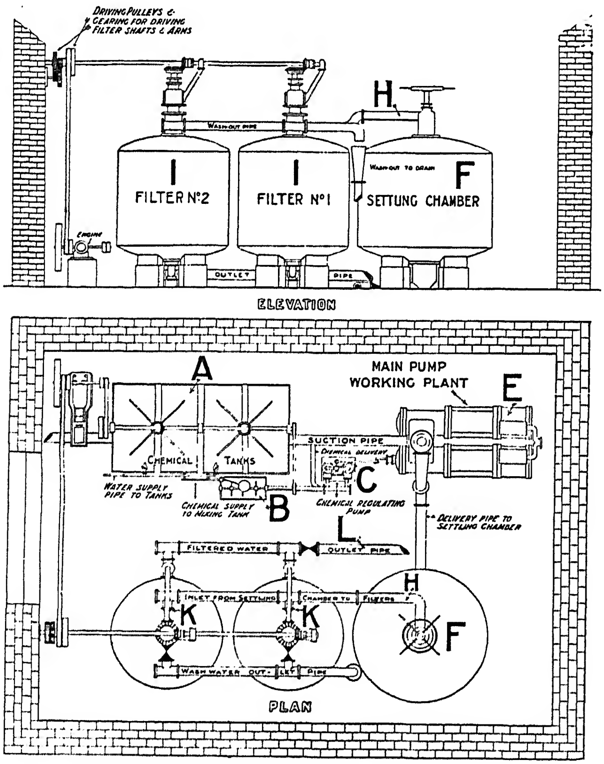


FIG. 73.—BELL'S WATER-SOFTENING PLANT.

(Messrs. Bell Bros., Ltd.)

Sedimentation is at best a slow process, and any device for accelerating it deserves to be recommended.

The finishing operation to remove residual carbonate in suspension is carried out by filtration. Both upward and downward flow through the filters have received a trial, and the former is less apt to cause clogging, and the sludge can

be more easily withdrawn. In any case the apparatus should be so arranged that the softener can be worked continuously; that is to say, it should not require to be put out of action while a filter is being cleansed. This is especially to be considered where water is being treated on a large scale for household use.

Water-Softening by Permutit; Removal of Iron, Manganese, etc.—An entirely new process of softening water has lately come into use in Germany through the application of artificial zeolites. Natural zeolites are common in rocks and soils, as representing one of the stages of disintegration. They are hydrated silicates of alumina holding some earthy or alkaline base in combination. If a zeolite composed of silicate of alumina and lime be brought into contact with a solution of common salt (chloride of sodium), the lime separates and the soda takes its place, provided that the sodium salt is well in excess of the quantity which theoretically the reaction would demand. We may express the exchange by an equation as follows:

$$\underset{\text{Calcium zeolite}}{CaAl_2Si_2O_8} + \underset{\text{salt}}{2NaCl} = \underset{\text{sodium zeolite}}{Na_2Al_2Si_2O_8} + \underset{\text{chloride of lime.}}{CaCl_2}$$

The reaction here described is a reversible one, as is readily seen when a soda zeolite is treated with water containing any salt of lime in solution. In fact, the silicate of alumina has a greater chemical affinity for lime than for soda, and the only reason for the separation of that base is the so-called "mass action" of the excess of the soda solution. Accordingly, if ordinary hard water be allowed to percolate through a layer of soda zeolite, the reaction set up is the following:

$$\underset{\text{Soda zeolite}}{Na_2Al_2Si_2O_8} + \underset{\text{sulphate of lime}}{CaSO_4} = \underset{\text{calcium zeolite}}{CaAl_2Si_2O_8} + \underset{\text{sulphate of soda.}}{Na_2SO_4}$$

On this reaction is based the new method of water-softening. Dr. Gans of Berlin has prepared artificial silicates of alumina and soda possessing the same properties as the natural minerals. He has introduced this to commerce under the name of Permutit, and has applied it with success to the removal of salts of lime, iron, and magnesia. Permutit is obtained by melting together felspar, kaolin, sand, or silica, and carbonate of soda in definite proportions. The melt is extracted with

water, and a crystalline body containing 46 per cent. of silica, 22 per cent. of alumina, 13·6 per cent. of sodium oxide, and 18·4 per cent. of water, is obtained. It is extremely porous.

In a test experiment Dr. Gans passed 9,000 gallons of hard water, with about 20 degrees of hardness, through a bed of Permutit in a continuous run of three days. The whole of the hardness was removed. The new salts introduced into the water—namely, carbonate and sulphate of soda—are unobjectionable both as regards the consumer and from an industrial point of view. Working costs compare very favourably with those of any other process.

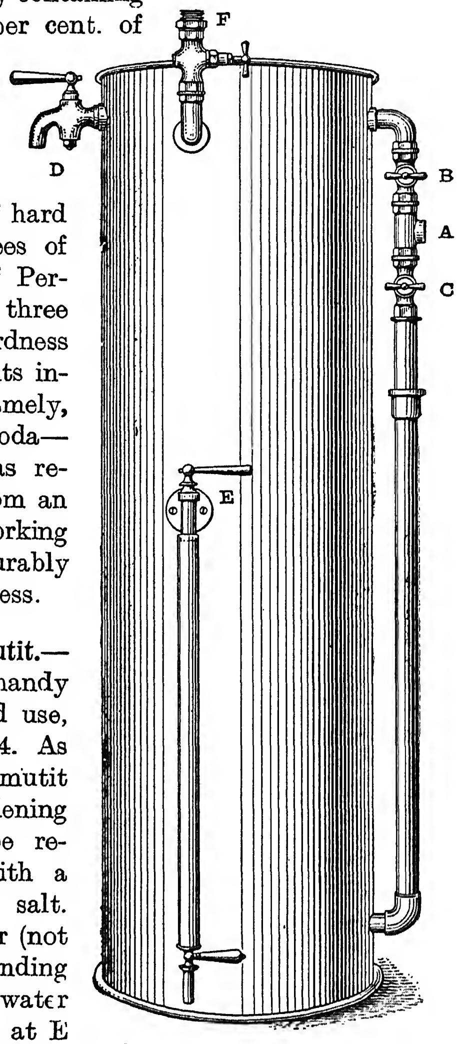


FIG. 74.—PERMUTIT WATER-SOFTENER.

A, inlet; B, valve to filter; C, D, wash-water inlets; E, outlet for filtered water; F, inlet for salt solution.

Regenerating the Permutit.—Dr. Gans has constructed a handy Permutit filter for household use, which is represented in Fig. 74. As might be expected, the Permutit gradually loses its dehardening properties, and it is to be regenerated by treatment with a strong solution of common salt. This is poured into a holder (not shown in the figure) standing above the filter. The raw-water tap at A is closed, and that at E is opened to empty the cylinder. The taps at D and E are now closed, and the half of the salt solution is allowed to flow in and rest in contact with the Permutit. After two hours a tap above F is turned, so as to let the rest of the solution trickle downwards at such rate that it may

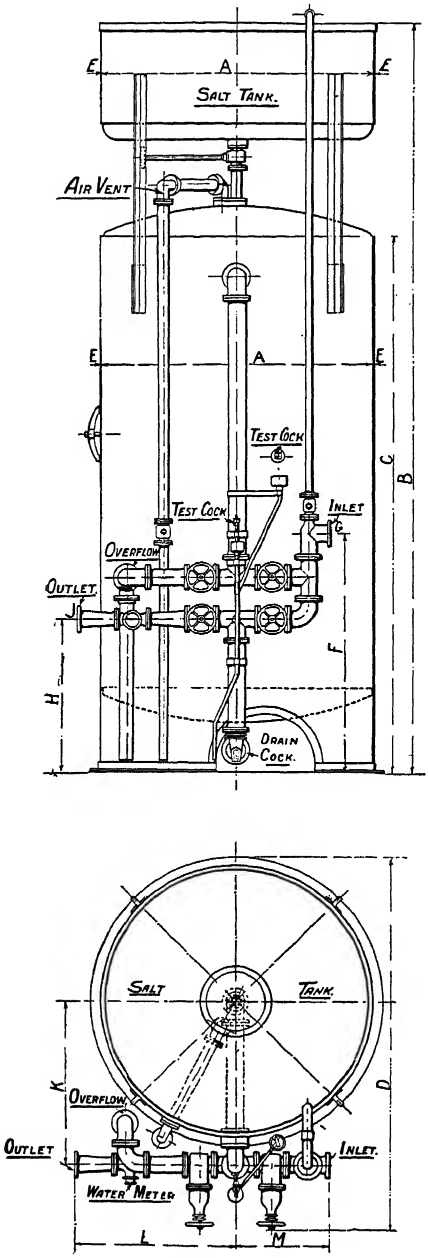


FIG. 74A.—SECTIONAL ELEVATION AND PLAN OF A PERMUTIT FILTER.

occupy six or eight hours in flowing away. Tap E is opened to about the same extent as F. This process may be arranged to go on overnight.

In the morning the wash-water taps D and C are opened, and the whole of the salt solution is washed out, carrying with it the very soluble chloride of calcium or magnesium that has separated in the reaction. The filter is now ready for work once more. This to-and-fro process of softening and regenerating causes no loss of Permutit.

Removal of Iron and Manganese.—For the removal of iron and manganese from water, Dr. Gans has prepared a manganese Permutit which consists of silica, alumina, and manganese, in a high state of oxidation. When water containing the lower oxides of iron or manganese in solution comes into contact with this body, they are oxidized by abstracting some oxygen from the manganese Permutit. Possibly, too, in the case of iron there may be a "catalytic action," the mutual influence of the higher oxide of manganese inducing the oxygen in the water to combine with the ferrous

salts. At any rate, the separation of iron is complete, and Dr. Siedler of Berlin, who discussed this system of dealing with iron at the Seventh International Congress of Applied Chemistry in London in 1909, referred to it as being both simple and elegant. Here again, if the manganese Permutit becomes exhausted, it may be renewed by treatment with a solution of permanganate of potash or of lime. There is no sludge formed, and hence the working expenses are much curtailed.

Water may be safely sterilized with this kind of Permutit. To the raw water sufficient permanganate is added, and the germs are destroyed. The whole of the manganese is then retained by the filter. Should it become overcharged with the higher oxides of manganese owing to the constant additions of permanganate, it is treated with a manganous salt, and is thus rejuvenated.

Calcium Permutit has found a useful application in the sugar industry, where it is employed to remove potash from syrup and molasses. Lime is left in place, but this is much less objectionable, and if desired the lime may be replaced by soda. The resulting sugar crystallizes better, and its appearance is improved. For industrial purposes Permutit has much to recommend it, as all undesirable minerals can be removed. This is very important for the manufacture of silk and woollen fabrics, because water holding magnesia or lime in solution forms compounds with soap—as stearate of magnesia, etc.—which are only washed out of the cloth with great difficulty.

Estimation of Hardness.—A simple method of estimating quickly the degree of hardness in water is described by Dr. Bäsch of Cologne.* Essentially it is a modification of the Clark process, which does away with technical niceties, and gives a satisfactory result in the hands of a person with no special chemical training.

A dropping flask of the kind devised by Boutron and Boudet is filled with a saturated solution of soap in alcohol. The same operators also use a hydrotimeter, so sealed that each division corresponds to 4 drops from their flask. When 10 cm^3. of water with 1 degree of hardness is treated with 1 drop of the soap solution, the hardness is neutralized. Two degrees of hardness demand 2 drops, 4 degrees 4 drops, and so on. The reaction is seen to be complete when, on shaking, a lather appears, and remains for four or five minutes.

* *Journal für Gasbeleuchtung und Wasserversorgung*, February, 1909.

CHAPTER X

THE TESTING OF WATER

The Bacteriological Examination of Water.

The examination of water for its living content has now come to be regarded as a matter of the first importance, for it is bacterial pollution which most quickly reacts on the health of the consumers and conveys to them the seeds of disease. Chemical analysis furnishes valuable information regarding the potability of a water, but the chief concern is to know whether the supply is or is not free from epidemic germs. The latter may find access to water accompanied with so little organic matter as would not arouse the suspicion of the chemist.

By a bacteriological examination one can best tell whether a filter is operating efficiently, for with one or two exceptions the dissolved substances are not greatly affected by the filtering media. But if the number of germs in the filtrate per cm^3. is steadily maintained at a low figure, and if dangerous types are not found in 40 or 50 cm^3., then one may assert that the filter is working in a trustworthy manner. The admittedly noxious types are those characteristic of sewage, as *B. coli*, or of morbid states, as *B. typhosus*, *B. enteritidis*, the bacillus of dysentery, cholera vibrio, and streptococci.

Apparatus for making Simple Bacteriological Tests.—No great technical skill, and no elaborate or costly apparatus, is required to enable any careful observer to make a simple and instructive test of the bacterial content of a supply, and very little time is needed to carry this out every day. There is reproduced in Fig. 75 a photograph of the laboratory in use at the Airdrie and Coatbridge Waterworks, which is modelled on that at Antwerp, where daily reports of the quality of the water are

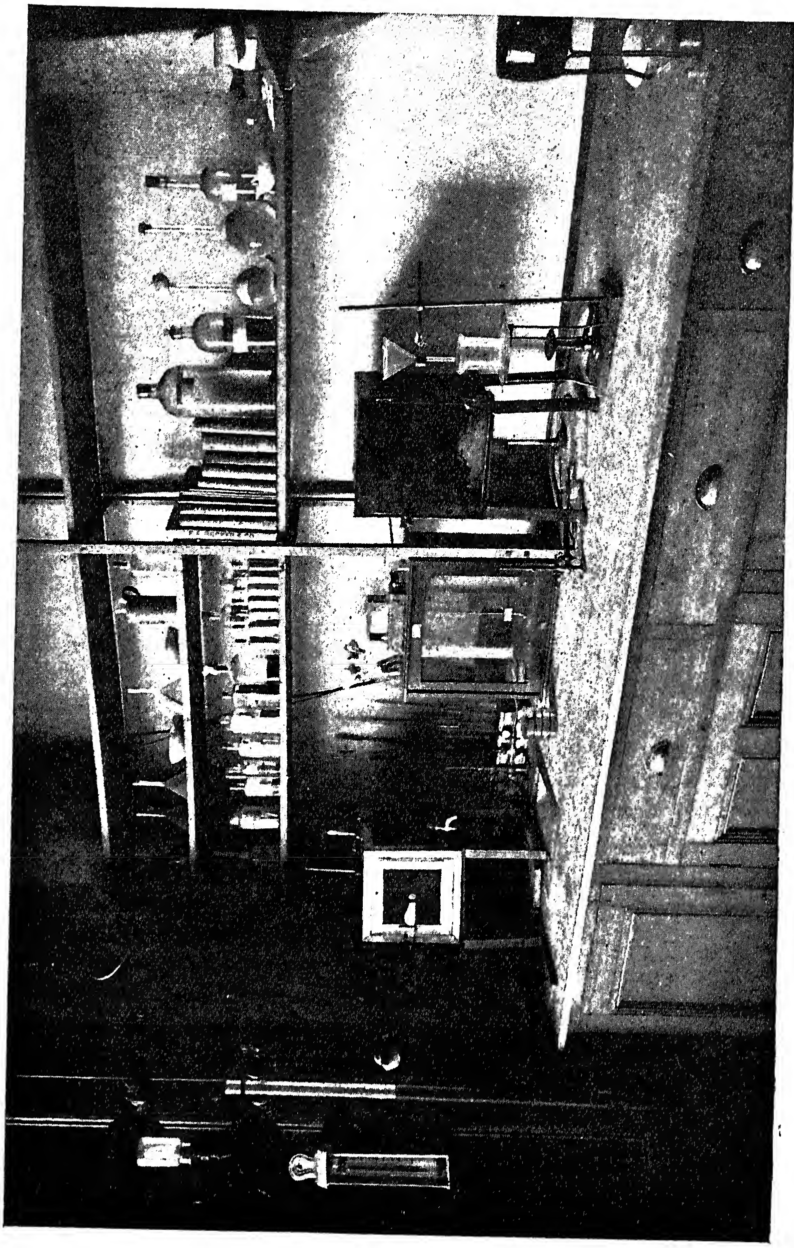


FIG. 75.—LABORATORY, AIRDRIE, COATBRIDGE, AND DISTRICT WATER WORKS.

prepared. The apparatus consists of an incubator (Fig. 76) with regulator (Fig. 78), a hot-air sterilizing chamber, one or two retort stands, Bunsen burners, and glass utensils, as burettes, beakers, pipettes, test-tubes, stock bottles, and Centigrade thermometers.

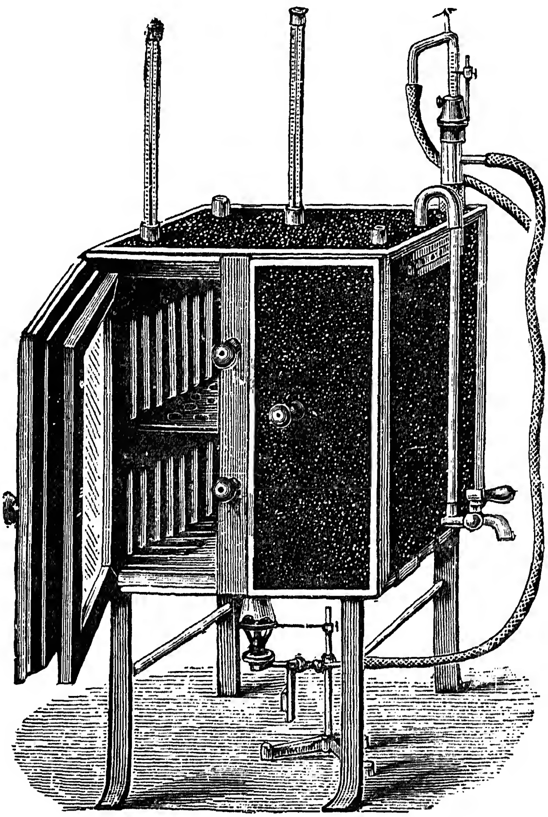


FIG. 76.—INCUBATOR WITH REGULATOR.
(Messrs. Thomson, Skinner and Hamilton, Glasgow.)

The nutrient gelatine in which the bacteria are cultivated may be obtained from wholesale chemists ready for use in test-tubes, or it may be purchased in quantity, and afterwards transferred to tubes in the laboratory. There will also be required a dozen or more Petri capsules, which are shallow glass basins, flat-bottomed, with covers to exclude dust (Fig. 77).

For gelatine cultures the temperature of the incubator should be kept at from 18 to 20° C., in order that the bacteria may have the fullest opportunity of developing; but some operators do not trouble greatly about the temperature so long as it does not fall below that of a comfortably heated room. In summer Dr. Kemna is able to dispense with the incubator, and even in colder weather he finds it sufficient to keep the Petri dishes in a cupboard near the fireplace. However, it must be remembered that if the temperature is not kept up to about 20° C. the culture proceeds more slowly, and there may be irregularities in the results. Therefore it is advisable for non-experts to set the incubator to 20° C. with the regulator supplied, and to carry out the cultures in the incubator at this temperature.

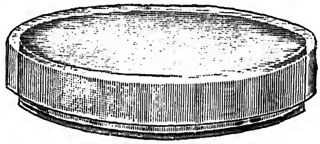


FIG. 77.—PETRI CAPSULE.

Temperature Regulator.—The regulator is a contrivance which lowers the gas flame when the temperature inside the incubator passes a limit previously fixed upon, and increases the supply of gas when the temperature sinks under the limit. Reichert's apparatus (Fig. 78) is interposed on the gas connection leading to the Bunsen burner under the incubator. The proper attachments are shown in the figure, from which it is seen that the gas enters at *a*, and descends to the opening at *c*, where the narrow end is cut across diagonally, so that the aperture is elongated. The exit to the burner is at *b*. The lower part of the regulator is formed like a thermometer, with bulb and tube filled with mercury. The height of the mercury is adjusted by the thumbscrew *d*, so that the surface of the mercury is brought to any required distance from the opening at *c*.

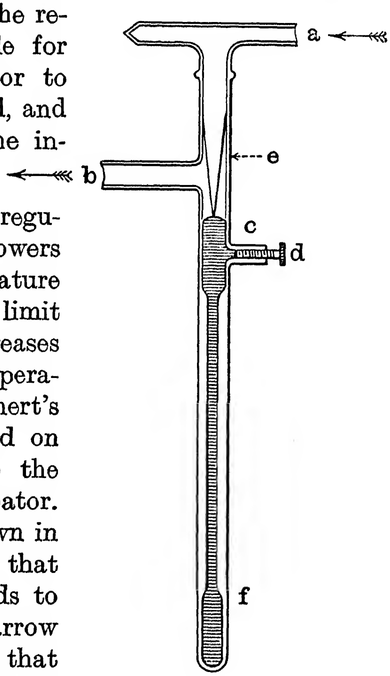


FIG. 78.—REICHERT'S TEMPERATURE REGULATOR.

The regulator is suspended in the incubator through an opening in the top, and acquires the temperature of the interior. If it has been previously set to cut off the gas at 20° C., the mercury will rise and just cover the aperture *c* when the temperature inside has come to that limit. The Bunsen burner is, however, provided with a by-pass, which keeps a small jet of gas alight when the main supply is intercepted. The by-pass may be supplied from a separate connection, or a pinhole may be pierced in the top piece of the regulator, as at *e*, so that the burner is never extinguished. Therefore, if the temperature falls, the mercury sinks and allows more gas to travel to the burner by way of *c*, and the flame is increased once more. With a little practice one is able to adjust the thumbscrew *d* for any required limit.

Method of conducting the Experiment.—In making the test, 1 cm^3. of the sample (or more or less, according to the number of germs expected) is run from a pipette into a test-tube containing about 15 cm^3. of sterilized gelatine, which has been brought to a liquid state by the application of a gentle heat. The cotton-wool stopper is replaced, and the water and gelatine are mixed with a steady turning and inclining movement, care being taken not to include bubbles of air. Still liquid, the mixture is poured into a Petri capsule which has been uncovered upon a level surface. A uniform spread of the mixture is thus obtained. The cover is quickly replaced, and when the gelatine has become firm the capsule is placed in the incubator at 20° C. for a couple of days.

The object of the above procedure is to distribute the germs through the whole volume of the gelatine; and if the mixing be properly done there will be no groups of bacteria in the gelatine, but only units scattered all over the film in the capsule. Individual germs develop into colonies, which after one or two days are quite visible to the eye as minute specs. They are counted by inverting the Petri capsule and examining the gelatine with the aid of a magnifying-glass. If the crop is too abundant, a smaller volume of the sample (0·5, 0·3, or 0·1 cm^3.) must be taken. There is a device for simplifying the enumeration, which will be noticed presently.

Precautions and Details.—There are numerous precautions to be observed in the course of the manipulation, to prevent

the access of foreign bacteria from the person of the observer or from the air. Details may be obtained from any standard work on bacteriology, but a few lessons in the laboratory will be of most practical value to the beginner. He will learn to beware of touching any part of the tubes or capsules with which the culture medium comes in contact. As the rim of the tube from which the liquid gelatine has been poured has been exposed to the air, it is necessary to sterilize that part by turning it round in the Bunsen flame for a little after withdrawing the cotton-wool plug. As soon as the rim cools—and the whole operation does not occupy more than half a minute—the contents are transferred to the capsule, the cover of which has been raised vertically to admit the mouth of the tube, and held in that position during the pouring, so as to intercept falling germs.

The period of two days has been given for incubation, but the capsules should be kept for a longer time. At the Paris Waterworks it is usual to observe them for fifteen days, both because there are types which develop slowly, and because the characteristic growths of certain types take time to manifest themselves clearly.

Colonies on the Nutrient Gelatine.—Examined with a good lens or with a low power of the microscope, the bacterial growths, or colonies, appear as dots or specks, mostly whitish, yellow, or grey, but occasionally brighter tints are noticed. They differ much in other respects. Some liquefy the surrounding gelatine, as do many of the so-called cocci, Rhine water bacillus, *B. fluorescens, liquefaciens,* etc. Some are rounded and granular, as *B. coli ;* other are irregular in contour, as *B. prodigiosus* and *B. aquatilis ;* and *B. nubilus,* which was found by Dr. Frankland in filtered Thames water, shows a tangled thread-like growth. *B. liquidus,* which is frequent in raw Thames water, forms cuplike depressions with liquefaction. *B. amylozyme,* which abounds in the crude supplies from the Seine and the Vanne, shows white dots surrounded by minute bubbles of gas. This power of liberating gas is not uncommon, and it serves as a distinguishing feature of importance.

The illustration (Fig. 79) shows the appearance of a Petri capsule with many colonies on nutrient gelatine.

Sterilizing and preserving Culture Media.—The sterilizing of apparatus preliminary to the tests is a necessary as well as a simple matter; all that is required being to place the glass utensils in the air-oven for half an hour at a temperature of 160° to 180° C. The gelatine tubes are sterilized by heating them in the air-oven or in a potato-steamer at the temperature of boiling water for a quarter of an hour on three successive days. The cotton-wool plugs should be firm and tight, and if a plug has been removed for any purpose, it should be slightly scorched before being replaced.

If a stock of gelatine has been procured, and it is desired to prepare tubes for cultures, a simple method is to obtain a

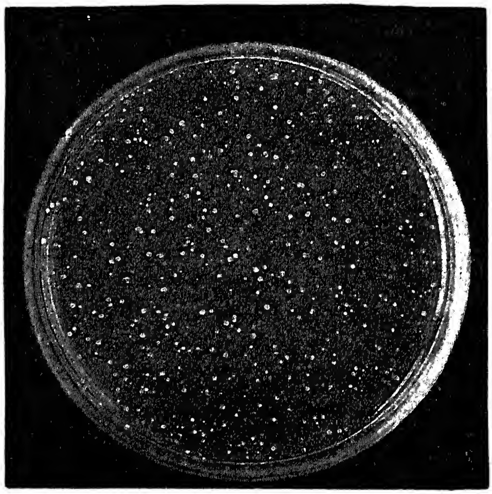


FIG. 79.—COLONIES OF BACTERIA ON GELATINE.
(By permission of the Lahmeyer Electrical Co., Ltd.)

wide burette holding 200 cm^3., which, after being warmed before the fire, is filled with gelatine previously melted by placing the stock bottle in hot water. The sterilized test-tubes are then brought one by one under the outlet, and about 15 cm^3. of the liquid run into each. One operator can do this rapidly if he holds the test-tube in his left hand, removes the plug by turning the back of his right hand to it and seizing it between the first and second fingers, and then turns the stopcock with thumb and finger of the same hand. When the desired quantity of gelatine has run in—and care must be taken not

to let the sticky liquid smear the sides of the tube near the top—the plug is scorched by passing it through the Bunsen flame, and pushed home. A dozen tubes may thus be filled in a few minutes. In the absence of a burette, the gelatine may be run in through a small funnel.

Steps of a Bacteriological Test in Sequence.—We shall now suppose that the operator, having obtained the necessary apparatus, desires to proceed with the experiments. He will have to observe the following instructions in sequence :

1. Wash several Petri capsules, drain, and sterilize them in the hot-air oven at a temperature of, say, 180° C. for thirty minutes. Sterilize also the pipettes for measuring the sample. As a rule these will be for 1 cm^3. A small burette is used for fractions of that volume.

2. Three gelatine tubes which have been previously sterilized as directed are placed in a beaker of water at a temperature of about 40° C., so as to make the contents entirely fluid. Meantime the Petri capsules are removed from the air-oven and allowed to cool on a level surface.

3. A 1 cm^3. pipette is now charged from the sample of water, and held in the right hand between the thumb and first two fingers. Taking a gelatine tube in the left hand, remove the plug with the second and third fingers of the right hand, turning the back of the hand to the tube in order to do this. Now thrust the end of the pipette into the tube, and allow the water to flow upon the gelatine. Withdraw the pipette and quickly replace the plug. Proceed to mix the contents by inclining the tube from side to side, at the same time turning it round on its long axis.* This must be continued for a minute or so, in order to distribute the water thoroughly in the viscous gelatine ; and if there should be any appearance of solidification, the tube must be returned to the hot water for a little. No bubbles of air should be formed, and with a little practice these can be avoided.

4. Again remove the cotton plug, which may now be laid aside. Give the mouth of the tube one or two turns in the Bunsen flame. Lift the cover of a Petri capsule vertically a few inches with the left hand, and with the other hand bring the mouth of the tube over the centre of the uncovered dish, and pour the contents steadily, avoiding any irregularity

* Alternately one may roll the tube between the hands, holding it vertically.

which would entangle bubbles of air. Now lay the tube aside, replace the cover of the capsule, and allow the gelatine to set. Then transfer the capsule to the incubator.

5. Two other capsules are to be charged with cultures in the same manner for the sake of comparison and control. They are all incubated at 18 to 20° C. for forty-eight hours, and then examined for growths.

6. To enumerate the colonies, invert a capsule without removing its cover upon a Pake's disc, and observe with a lens or with a low power of the microscope. The Pake's disc is simply a circle of blackened cardboard of the same radius as the capsule, divided into sixteen equal sectors by white lines radiating from the centre. It is well to count the colonies in three or four sectors at different quarters, and then calculate for the whole area. The observer should make special note of the number of colonies which liquefy the gelatine, because these are often of an objectionable type. But it must be remembered that neither *B. coli* nor *B. typhosus* cause any liquefaction.

7. The capsule after examination is to be replaced in the incubator, and kept for inspection up to the fifteenth day, when it is to be cleaned and sterilized for further use.

Tests for B. Coli and Pathogenic Species.—By far the greater number of bacteria found in water flourish best at a temperature of 20° C. or thereby, but they are able to develop more or less rapidly at temperatures removed from this optimum. With exceptions to be mentioned presently, the range of temperatures for water bacteria is from 0° to 30° C., and it is to be understood that the nearer these limits are approached the more feeble is their growth. But those species of bacteria in water which are derived from man and other warm-blooded animals can multiply at temperatures between 10° and 45° C., with an optimum of 37° to 38° C.—that is, at blood-heat. These are of the highest interest to water undertakers, seeing that it is with their presence that the pathogenic character of the water content is associated.

Since the water bacteria that are commonly regarded as harmless do not grow at blood-heat, it is possible to exclude them altogether and restrict attention to pathogenic forms. For this a special medium is required, because gelatine becomes

liquid at temperatures above 25° C. Instead there is employed a mixture of nutritive substances with a particular seaweed known as "agar," which liquefies at 98° C., and on cooling again becomes solid at 39° to 40° C. Exposure to temperatures over 42° C. would be likely to injure the organisms we are in search of, so that if one proceeds to mix the sample of water with the fused agar medium, care must be taken first to cool the contents of the tube down to 42° C. This leaves a very narrow margin of time to work upon for the double process of mixing and pouring. Agar media are also more clammy and difficult to pour if solidification has made a beginning around the sides.

Concentration of Germs from Large Samples.—On account of these circumstances, few bacteriologists now adhere to the method of mixing the sample of water with the agar culture medium. In any case, with water which is moderately pure, one would not look for many pathogenic bacteria in 1 cm^3., so that 10, 20, or even 100 cm^3. must be put to the test. To deal with the larger volumes, it is usual to concentrate the bacteria by throwing them down with a colloidal precipitant like alumina, by filtration through unglazed porcelain, by evaporation under reduced pressure, or by centrifugalizing. The latter method is recommended by Dr. Houston. The residue obtained in one or other of these ways may now be dealt with as follows :

A Petri capsule is sterilized and placed on a level surface. The contents of an agar tube are liquefied in boiling brine and poured into the capsule, the entrance of dust being avoided in the manner already indicated. The concentrated bacteria and other suspended matter in a semi-liquid condition are spread over the agar when it has set firm, and the capsule is then transferred to the incubator, which is regulated to a temperature of 37° C.

The spreading of the concentrate over the agar requires attention. We may suppose that the measured volume has been treated with a few drops of sulphate of alumina, allowed to stand for a little, and filtered through a porcelain block under cover, to exclude falling germs. The cover of the Petri dish is raised by an assistant, and the residue on the filter is transferred to the agar with a platinum brush with the aid of

a few drops of sterilized water. It is then smeared evenly over the surface, the brush is finally rinsed with a drop of water from a pipette, and the cover of the capsule replaced.

Of the types which grow at the higher temperature, there may possibly be some that are innocuous, but in general they are suspicious, and are indicative of sewage pollution. The agar medium for this test had better be obtained in test-tubes ready for the experimenter. There are many recipes for the preparation, but one of the best is given in Dr. Houston's reports on his researches on the vitality of bacteria in water. It contains the following ingredients, stated in parts per 1,000 (grammes per litre): Agar and peptone, each 20; bile salt, 5; dulcite, lactose, saccharose, and salicin, each 2·5; and 4 cm^3. of neutral red. The medium suggested by Drigalski and Conradi is of slightly different composition, containing a little meat extract, and the colouring matter is kristall violet. On this the *B. coli* form colonies which are of a red tint, and thus are distinguished from other types. Dr. Federolf (*Arch. f. Hygiene*, 1909, Bd. 70, p. 311) advises the use of the latter culture medium, and he also propounds a method for searching a large volume of water at a time. One litre ($1\frac{3}{4}$ pints) of water is made alkaline with 4 cm^3. of a 10 per cent. sterile soda solution, and is then treated with 3·5 cm^3. of a 10 per cent. solution of ferric sulphate as precipitant. The precipitate is allowed one hour to settle in the cold, then centrifugalized, separated from the liquid, and dissolved in a 25 per cent. solution of acetate of soda. This concentrated solution is then spread in volumes of about 1 cm^3. over the Petri dishes (five may be needed), charged with the Drigalski-Conradi agar medium. From the red hue of the colonies of *B. coli* Dr. Federolf finds no difficulty in enumerating these. He has been able to show the presence of *B. coli* when the water contained no more than 7 individuals in 1 litre.

In conclusion, it may be repeated that the bacteriological tests as indicated here are as simple as they are instructive. The outlay for apparatus need not exceed £20, the costs of working are trifling, and the time required for the daily experiments may amount to an hour when the effluents of four or five filters are to be examined. Such time is well spent, for the water manager is enabled to keep a record of the efficiency of the various filters, and he is led to seek a remedy if defects

are indicated. He is no longer working in the dark. He discovers the conditions on which the good or bad working of his plant depends. Bacteriological tests have led up to the improvements which have made the installations at Paris, London, Amsterdam, Berlin, and Cherbourg, not to mention other places, the reliable agencies for purification which they now are. The application of these tests also enables the water manager to know if the water on its arrival at the consumers' taps has retained the standard of purity which it possessed when it was introduced to the mains.

CHEMICAL ANALYSIS OF WATER.

General Characters; Turbidity.—The transparency of filtered water, its taste and odour (if any), are three qualities which come under the scrutiny of consumers, and it is most desirable that the water should give complete satisfaction so far as these obvious characters are concerned. The service water must not be insipid or "dead"; it should be thoroughly aerated. A good process of purification, in removing organic matters in suspension, and reducing the amount of putrescible substances in solution, usually eliminates any odours originally present. But precautions are necessary against growths of blue algæ, crenothrix, etc., which would impart a disagreeable smell to the effluent.

The turbidity of filtered water is more often due to dissolved colouring matter than to finely divided sediment. Sand-filtration does little to remedy the loss of transparency due to the presence of peaty acids. But peaty water when treated with a coagulant becomes perfectly clear, and other substances which discolour the water, as iron oxide, can usually be got rid of by special appliances. It is desirable to have at hand a means of gauging the transparency of water, so that one may judge of the efficiency of any process of clarification, and of the suitability of a natural source for domestic purposes.

Standards of Turbidity.—In Britain and America certain standards of turbidity have been in use, commencing with distilled water. A scale is arrived at by adding 1, 2, 3, etc., grains of finely pulverized silica to separate vessels containing 1 gallon of distilled water. There are several methods of com-

paring the transparencies of these samples so as to make the scale applicable to waters generally. One method consists in bringing the samples one by one into a deep cylinder in good daylight, and observing the depth at which a platinum wire, $\frac{1}{25}$ inch in diameter, is visible to the naked eye of a person of normal vision. With slight turbidity—say 1 grain per gallon—the wire is distinct at a depth of 3 feet. With twice that turbidity the wire is visible at rather more than half the distance. The depths at which the wire is distinctly seen are not quite proportional to the turbidities of the samples. The United States Geological Survey has adopted a scale of turbidities in which the index number 100 is given to a water in which the $\frac{1}{25}$-inch platinum wire is visible at a depth of 100 millimetres (4 inches). A few readings of the scale are given in Table XIV.

TABLE XIV.

Depth of Wire in Millimetres and in Inches.	Turbidity.
1,095 millimetres, or 43 inches.	7
587 ,, ,, 23 ,, ...	14
426 ,, ,, 16¾ ,, ...	20
296 ,, ,, 11¾ ,, ...	30
158 ,, ,, 6¼ ,, ...	60
130 ,, ,, 5⅛ ,, ...	75
100 ,, ,, 4 ,, ...	100
76 ,, ,, 3 ,, ...	140
57 ,, ,, 2¼ ,, ...	200
31 ,, ,, 1¼ ,, ...	500*

To obtain a reasonable uniformity in the estimations, Hazen recommends that the cylinders should have opaque walls, and that the observations be made about midday, but not in direct sunlight. Otherwise the water may be illuminated in a dark room by a lamp of known candle-power situated so that the rays pass down through the water, the observer's eye being behind the source of light and shaded from it.

It is found that distilled water containing 100 parts per 1,000,000 of fine silica of a certain grade has a turbidity of 100. That particular grade is regarded as a standard of fineness. This leads to the conception of a "coefficient" of fineness—that is to say, the quotient of the ascertained weight of suspended matter per 1,000,000 (here milligrammes per litre) by the number found for the turbidity. When this coefficient is

* See further, *Water*, p. 434, 1904.

greater than unity, the inference is that the grade of the suspended matters is coarser than the standard ; and if less than unity, the grade is finer.

Turbidimeters.—The instrument employed to make the test consists of a rod 5 feet long, with a platinum wire, $\frac{1}{25}$ inch in diameter and 1 inch or more long, projecting from near one end, at right angles to the length. The rod is graduated according to the table of turbidities. The observer looks through a ring fixed to the rod at a distance of 4 feet above the platinum wire. Waters with a turbidity over 500 are diluted with distilled water, allowance being made for that in the reckoning. A simple and ingenious instrument for measuring transparency is described in *Eau et Hygiene* (Puech-Chabal, Rue Ampère, Paris), January, 1909. A rectangular tube (Fig. 80) blackened internally is divided into two equal parts by a longitudinal partition. One end is closed by a plate of ground glass, while the other is somewhat contracted and lengthened out to form an inspection opening, or "eyepiece," E, but it carries no lens. An eye looking into this end can see down both compartments of the tube at the same time.

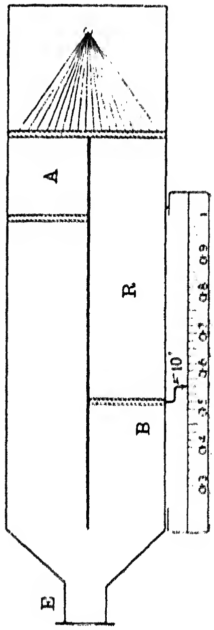


FIG. 80.—PHOTOMETRIC TURBIDIMETER.

Within one compartment a closed space, A, is formed next to the ground glass for the reception of the water to be tested. This chamber may be about one-fifth of the total length, and its inner wall next the eyepiece is also of ground glass. In the second compartment there is a movable screen of ground glass, B, which can be made to travel backwards and forwards by means of a longitudinal screw. A pointer indicates the position of this screen on a scale affixed to the outside of the tube.

Suppose now that a sample of water of known turbidity has been placed in the receptacle provided for its reception, and that a light is set behind the end of the tube which carries the ground glass. An observer viewing the interior of the tube

from the other end sees two screens, the one illuminated by light which has traversed the water, the other by rays that have passed through an air-space, R. By adjustment with the screw he brings the movable screen to a position such that the illumination in both compartments is equal. When this has been done, the graduation of the instrument can be made as a consequence of the fact that the intensity of a beam of light decreases as the square of the distance of the object illuminated from the source of light. Thus, if the sample of turbid water be replaced by one charged with *four* times the quantity of sediment, the movable screen must be set at *twice* the former distance from the ground-glass plate at the extremity of the tube.

This turbidimeter can easily be used either with an artificial illumination or with daylight, as the accuracy of the readings is not affected by any difference in the intensity of the external source of light.

A method which gives satisfactory readings dispenses with the platinum wire. A standard candle is placed at a distance of 3 inches below the transparent base of the test cylinder, and so much of the sample of water is poured in as is sufficient to cut off the light passing upwards. By experiments with prepared samples of distilled water containing various amounts of silica in suspension, a scale of turbidities can be determined.

Other instruments depending in principle on one or other of the laws of optics have been devised for the more exact measurement of turbidity. Mr. Chas. Anthony's diaphanometer takes advantage of the fact that a beam of light passing through two Nicol's prisms in sequence is diminished in intensity by rotating one of the prisms. The diminution is strictly proportional to the angle through which the Nicol is turned. A beam of light is divided into two equal parts, and one is directed through a tube containing the sample of water, while the other travels by way of the prisms. The observer judges by the eye the relative intensities of the two beams, which are made to illuminate two screens placed side by side. Equality is obtained by rotating the movable prism. By using samples of known turbidity a scale can be adjusted.

The following simple experiment affords very instructive indications. It was shown to the writers at Waelhem by Dr. Kemna.

test-tube, 9 inches by ¾ inch, is filled to a depth of 7 or hes with the water to be examined. A number of samples ifferent turbidities—crude water, outflow from *dégrossis*-, samples from best, the worst, and average filtrates—were d in test-tubes for the purpose of comparison. The test- were ranked in a stand side by side, the bottoms resting pressions painted black, so as to cut off the access of light below. On looking into the tubes, it was seen that the *worst* sample appeared to be the clearest. At any rate, light proceeded from it, because the only rays which could the eye were those which had passed more or less hori-lly through the walls of the tube, and had been reflected by uspended particles. Hence, a tube which looked bright this arrangement was known to contain water charged many floating particles. The best sample appeared to be dull. It contained no objects that could reflect light rds to the eye.

interesting variation of the experiment is this: Remove st-tubes from the stand, and place them so that light can freely from below. The worst samples now, of course, r darkest, and by covering the outside of the tube, with ception of the bottom, with a black cloth the contrast is ified. This is due to the intercepting of the rays, which, ng the tubes horizontally, are reflected upwards. The r the quantity of suspended particles, the greater will be ffect of obscuring the tubes in this way. With a fairly water the amount of light reflected from floating particles ll. Most of the light which reaches the eye comes through ttom of the tube, so that cutting off the side-rays makes difference.

uence of Turbidity on the Life of the Sand-Filter.—Trials nade by the Pittsburg Filtration Commission to estimate e of a filter under varying conditions of turbidity. As a re of turbidity in general, the submerged platinum wire sed. When this could be seen at a depth of 1 inch only, rbidity was reckoned as 1·00, at 2 inches 0·50, at 10 inches The filter-bed under experiment was composed of of fine sand, and with an average turbidity of 0·051 (wire isible at 20 inches) a column of water 400 feet long was pass before the head rose to 4 feet. When the turbidity

was doubled the column shortened to 270 feet, and when it was once more doubled the column was reduced to 180 feet. The formula deduced is that the period between scrapings calculated in million gallons per acre $= \frac{12}{\text{turbidity} \times 0{\cdot}05}$.

Colour of Water, and its Measurement.—For the purpose of comparing the colours of samples of water, Allen Hazen has prepared a series of tinted glass discs which are to be viewed alongside the water under examination. Two glass cylinders, 10 inches deep and 1 inch in diameter, are taken. One is filled with the sample previously filtered through good filtering-paper or porous porcelain. The second tube is fitted with a clip for holding one of the coloured discs. It may be filled with distilled water or not, as the observer chooses. The tubes are then held about 8 inches from the eye, side by side, and a coloured disc is selected to match the tint of the water. Behind the tubes is a well-illuminated white surface, and the observer should look at both tubes with one eye. The test must be made in daylight.

The colours of the discs correspond with the tints of graded solutions of potassium platinic chloride to which has been added cobalt chloride. One litre of the solution contains 0·5 gramme of platinum and 0·25 gramme of cobalt. By dilution, standards representing colours of various depths of tint from 0·05 of the original up to 0·7 are obtained.

Total Solids.—The amount of total solids in natural waters varies with the source. Upland surface water contains 9 or 10 parts per 100,000, ordinary river water two to four times as much, and wells and springs may hold little or a considerable amount, according to the geological formations from which they are supplied. There is no accepted limit to the amount of suspended solids. Obviously, if the water is otherwise of reasonable purity, and if filtration is not attended with any special difficulty, a water like that of the Nile or the Mississippi may be drawn upon with good results. The total solids having been obtained by evaporation of a measured quantity of the sample at 100° C., some indication of the nature of the solids in solution and suspension is got by heating. Mineral substances do not change colour in any very noticeable manner, but organic matter may blacken or char; it may give a dis-

agreeable odour, or it may be decomposed and driven off. Any loss of weight consequent on heating the dried residue is usually attributed to organic matter. The odour of vegetable matters when ignited is somewhat pungent, and the same may be said of substances of animal origin, but the effect on the senses is generally more disagreeable.

The salts dissolved in natural waters are chiefly carbonates of lime, magnesia and soda, and chlorides, and sulphates of lime, magnesia, soda, and potash. Moderate quantities of these are in no way detrimental to the potability of a water, and a certain proportion of lime is considered to be an advantage.

Waters drawn from the chalk and marl beds, common in England, France, America, and elsewhere, are heavily charged with salts of lime, and a process of "softening" becomes desirable. In Essex, according to Dr. Thresh, the water-supplies contain much carbonate and sulphate of soda, which are not looked upon as harmful.

In addition to these salts, many natural waters contain minute proportions of other compounds, as nitrates, nitrites, salts of ammonia, organic bodies, as urea, colloidal bodies, humic and crenic acid, phosphates. The presence of nitrates and nitrites is (in most cases) significant of the addition of liquids which at an earlier period of their history were in contact with decomposing animal matter. In the analysis, therefore, special attention is given to these compounds. When nitrites are found to occur, the inference is that the contact with organic pollution has been recent. As mentioned elsewhere, the fact that nitrates have been found in, say, river water, even in excess of the average amount, does not in itself warrant the analyst in asserting that the supply is polluted. This knowledge must be correlated with an examination of the source of supply and with the bacteriological results before any scientific conclusion can be arrived at.

We proceed to deal with the inferences that appear to be deducible from the occurrence in certain proportion of the most important constituents.

Chlorides.—These are normally present in all waters, whether from the surface, or from wells, borings, or springs, but the amount that goes into solution depends on many circumstances. The nature of the rock minerals has an important influence, but,

except in special districts where beds of salt occur, it is not usual for the natural waters to dissolve more than a very few parts per 100,000. Soils near the sea receive additions of

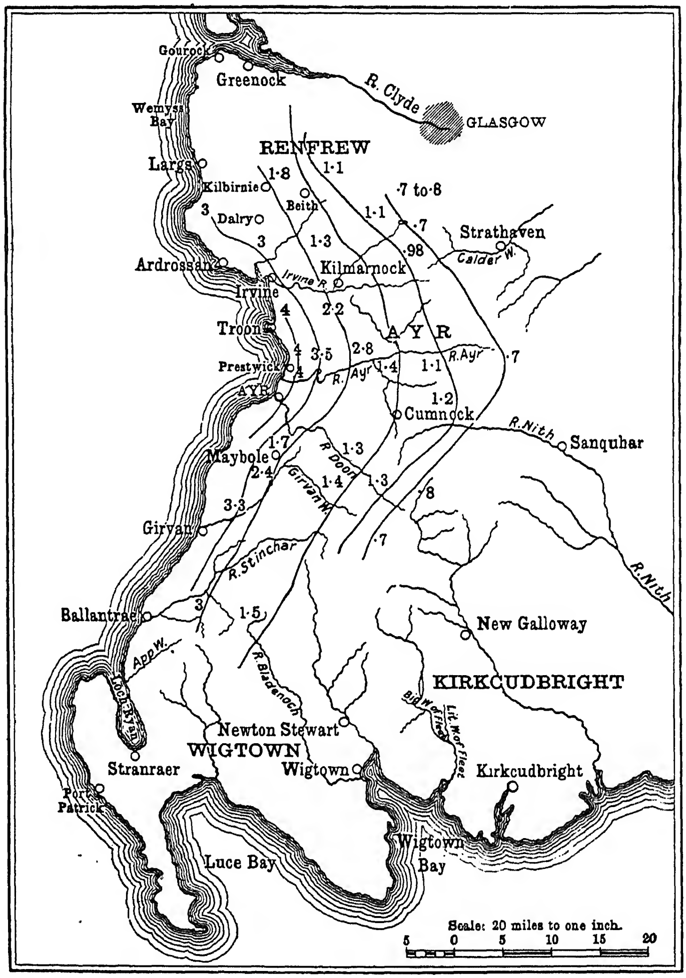


FIG. 81.—LINES OF EQUAL CHLORINE CONTENT (ISOCHLOR LINES) IN GROUND WATER SUPPLIES.

chlorides from blown spray and spindrift, and to some extent there is a percolation of salt water from shores and estuaries. An increased proportion of chlorides may be expected in the vicinity of salt water. In the map (Fig. 81) an attempt is made

to plot the lines of "equal chlorine content" so far as regards the natural waters of a particular district. Sources known to have been polluted are not taken into account.

It may be safely inferred that, wherever a source yields an amount of chlorine far in excess of that marked on the isochlor line to which it is approximate, there is ground for suspicion, and good cause for careful inspection. The urine of animals contains from 500 to 600 parts in 100,000 of chlorine, and even when diluted with much water the amount of chlorine is conspicuous in the analysis. In sewage there is, roughly speaking, an admixture of 1 part of urine with 100 parts of water, so that the ingress of 20 per cent. of sewer effluent would raise the contained chlorine and the supply water by 1 part per 100,000. Hence, while gross pollution is pretty clearly betrayed by excess of chlorine, small additions of sewage arouse no suspicion on this score. Dr. Thresh has calculated that the sewage from a population of 1,000 souls might be regularly distributed over 600 acres of porous soil without increasing the chlorine in the subsoil water by more than 0·3 part per 100,000. But he concedes that within areas where the geographical formations are known to be uniform, a decided increase in the chlorine content of a well or other source is attributable to pollution, recent or remote. The distributing of farmyard and other manures on the land exercises an influence on the salts dissolved in the drainage water. Seasonal variations in the chlorine content of streams and of underground sources adjacent to cultivated lands may be anticipated, and this is found to be so. The addition of much rain water often lowers the percentage of chlorides in wells. From this circumstance, Dr. Thresh has occasionally been able to trace the contamination of water from a deep source to the ingress of surface water.

The presence of sodium chloride to the extent of 50 parts per 100,000 does not seem to be objectionable, but chlorides of magnesium or calcium are on a different footing, as they decompose soap, and they might not be innocuous from a hygienic point of view. If from the analysis it be inferred that more than 4 parts of magnesium or calcium chloride are indicated, attention should be drawn to probable consequences.

Nitrates.—There is a rough and ready rule which is applied by certain analysts for estimating the percentage of sewage

(or its equivalent) which, when mixed with water of ordinary purity, would occasion the degree of pollution which has taken place. The rule is based on the estimation of nitrates, and deduces that the volume of sewage in the water is equal to six times the parts of nitric acid per 100,000. Crude sewage, according to Dr. Thresh, as it occurs in the drains, may contain 12 to 16 parts of nitrates per 100,000, and a purer water contaminated with 6 per cent. of such sewage would give about 1 part of nitrate per 100,000. The rule as applied is practically useless, for after nitrification has been completed by percolation the amount of nitrates in the effluent from filter-beds is often as high as 45 to 50 parts per 100,000. The mere estimation of nitrates without any regard to the source might lead to the conclusion that a seemingly large volume of crude sewage had found its way into the supply, whereas the real origin might be the comparatively harmless effluent of sewage purification. However, there seems to be little doubt that nitrates in soils and natural waters owe their existence to the decomposition of animal matter. An ever-present by-product of the disintegration of such matter is ammonia, which is converted, under suitable conditions, into nitrous acid and nitrites by nitrifying bacteria. Such conditions are readily found in the soil, in porous strata, clinker-beds for the treatment of sewage, and to a less extent in sewers and streams. Slow percolation through a few feet of gravel will convert nearly the whole of the nitrogenous matter in sewage into nitrates (see River Pollution Commission Report).

The next step is the conversion of nitrite into nitrate by ordinary oxidation ; therefore the presence of nitrates in supply water may very well be due to this natural cycle of organic change. The very process which favoured the formation of nitrates—viz., percolation and aeration—may also eliminate the impurities which would render the water unsafe ; that is to say, in the passage of the contaminated liquid through soil or porous strata it is, to say the least, likely that most of the bacteria have been left behind. In fact, many well waters containing nitrates are found to be of great bacteriological purity. The presence of nitrates does not warrant the analyst in forming any opinion of a water distinctly favourable or unfavourable. It may contain organic bodies that have had no opportunity of decomposing, and objectionable bacteria in company. The

presence of nitrates in excess of the average amount to be expected from the source is to be looked upon merely as a danger-signal. The nitrates *per se* are not harmful, but the fact that their presence has been proved indicates but the need of further inquiry and experiment.

Nitrate Content as a Standard of Purity.—Standards of purity are given by many authorities regarding the nitrate content. The limit that may be supposed to mark off the non-suspicious waters is variously given as 0·4 or 0·2 part per 100,000. Such standards cannot be regarded as having any general application, even in the estimation of those who attach the greatest importance to the nitrate results. Nor would any good purpose be served by giving standards for river water, well water, surface water, and so on. River waters differ much in their nitrate content. There are seasonal variations, according to the amount of manure distributed within the reach of their tributaries. Wells have no constant charge of nitrates. Dr. Thresh mentions that the content of several deep wells far exceeds any limits defined, and Dr. Munro (*Journ. Chem. Soc.*, 1886) thinks that well water must contain a trace, unless there has been an introduction of fermentable matter which would destroy or de-nitrify the nitrates. The latter authority is therefore inclined to regard the total absence of nitrates, in waters that have some opportunity of percolation, as not beyond suspicion. In reality it is futile to rely on this item of the chemical analysis as a datum from which to deduce whether there has been remote pollution, or recent, or none at all. Dr. Thresh states that there are villages that have been using water with 2 to 5 parts of nitric nitrogen per 100,000 (9 to 22·5 parts of HNO_3), which have yet been quite free from water-borne diseases; and, on the other hand, serious epidemics of typhoid have occurred in places where the water-supply contained very small quantities of nitrate. Dr. L. Weysen, Antwerp ("Eaux d'Égout et Nitrates," Anvers, 1908), contends that the effluent of a sewage treatment works cannot be looked upon as biologically purified unless it contains a considerable amount of oxidized nitrogen.

Nitrites.—There is one probable and several possible sources of the presence of nitrites in natural waters. Sewage in its natural state, and sewage partly and imperfectly treated or

acted on by agencies which naturally purify it, contain nitrites. The occurrence of nitrites, therefore, at once suggests recent pollution, attended with serious danger. Very small amounts, constituting only what chemists call "a trace," have therefore a special significance to the analyst. If the presence of nitrites in a service water is proved, an all-round examination is imperative, embracing the bacteriological analysis and a review of the means adopted for protecting the gathering grounds and other units of the installation from pollution. In the course of this investigation it may be discovered that one of the sources referred to above is accountable for the presence of nitrite.

Among other possible causes, the action of certain metals in the pipes or cisterns may be referred to. Iron, zinc, and lead, all possess some power of reducing nitrates to nitrites by the abstraction of an atom of oxygen from the nitrate molecule. Perfectly wholesome water containing nitrates in solution may therefore show signs of nitrites after being in contact with these, more especially in new fittings exposing fresh metallic surface. A comparison of samples drawn at the source and at the consumers' taps will indicate whether any such reduction has been in progress. The reduction of nitrate to nitrite may also be due to the activity of bacteria. According to Dr. Munro (*Journ. Chem. Soc.*, 1886), sewage contains species of bacteria which actively perform this operation. He further explains that the access of fermentable organic matter is responsible for the disappearance of both nitrate and nitrite from water, but that the latter represents the intermediate and incomplete stage. The fact that nitrites may be the indirect outcome of sewage or other putrescent matter does not, therefore, modify the serious significance of their presence in a supply water. It is not too much to say that a water in which nitrites occur should be provisionally condemned as being unsafe and impotable until the origin of the whole of the impurity has been ascertained.

Ammonia and its Compounds (Inorganic Ammonia).—Rarely absent from natural waters, this constituent occupies an important place in the analysis, because an excess of it beyond certain conventional standards is frequently believed to indicate dangerous pollution. The inferences, however,

which one arrives at by comparison with a chosen standard are misleading, because the amount of ammonia in natural sources of pure and potable waters varies greatly. The usual limit is 0·005 part per 100,000, and it is to be remembered that rain water holds far more than this in solution on the average (Thresh, "Examination of Waters and Water-Supplies," p. 89), and that upland surface and peaty waters may contain 0·01 part per 100,000.

Free ammonia and its compounds are derived in abundance from the decomposition of organic substances, urine, excremental matter, and from the decomposition of all kinds of dead animals. Hence, the analyst who has discovered excess of ammonia must again turn his attention to the source from which the sample has been obtained. He will naturally test the water for organic matter in solution or suspension, and he will make inquiry into the antecedents of the supply water. Ammonia finds its way into water from sources which are not looked upon as dangerous. It results from the decay of plants, and from the reduction of nitrates through the agency of vegetable types (algæ, etc.). It is carried down from the air, as has been mentioned. The reducing action of metals on nitrates and nitrites may lead to the formation of ammonia as a final degradation product. While a general standard of the ammonia content of a water is inadmissible, it may be profitable to state summarily the amount that may be looked for in various classes of water. In spring water and in that which comes from deep wells there should be very little ammonia, if the whole supply has percolated slowly, because the nitrifying organisms in the soil convert ammonia into nitrates. Upland surface water and rain water may contain considerable quantities, and 0·01 part per 100,000 need not be regarded as suspicious. River waters should not hold more than 0·005 per 100,000.

Albuminoid Ammonia.—When organic matter containing nitrogen is distilled with an alkaline solution (soda, potash, etc.) to which has been added a quantity of permanganate, various chemical changes result whereby the nitrogen is partly or wholly converted into ammonia, which then passes over, and may be collected and estimated. The sample to be tested is first freed from all ordinary ammonia existing in the

water as such. The alkaline permanganate on boiling breaks up organic matter and liberates more ammonia. In this way a measure of the organic impurities in the water is obtained by help of the "albuminoid ammonia," which is to be regarded as an empirical gauge. For the organic compounds which are found in water do not all yield with equal readiness to the above-mentioned reaction. According to the Massachusetts State Board of Health, the albuminoid ammonia is only about one-half of the total amount which the organic matter should yield theoretically. Certain readily decomposable compounds may give up the whole of their nitrogen in the form of ammonia, but the method of analysis does not indicate in what proportion these may actually be present. But, further, it is impossible to determine in this way whether the organic matter is wholly of vegetable origin or wholly of animal origin. If, as usually happens, both sources have contributed, we cannot tell in what proportions they coexist. Still, the determination of albuminoid ammonia, when correlated with other analytical results, is believed to be capable of guiding the chemist to conclusions regarding the safety of the water sampled, and this view must be regarded as being scientifically sound.

In the first place, the amount of albuminoid ammonia in potable waters is in general at least equal to the quantity of free ammonia, and very often it is two or three times as much. Sewage-polluted waters usually contain more free ammonia than albuminoid, and consequently an excess of the former over the latter is suspicious. A comparison of results might therefore serve to indicate cases of pollution. It would be unnecessary to stop to consider the relative proportions of the two ammonias if much foul matter is present, seeing that the excessive amount of either free or albuminoid matter would of itself reveal the state of affairs.

Again, by means of "the oxygen-consumed" process, or by other modes of analysis, the analyst can estimate the amount of organic carbon in the organic matters in the samples. Nitrogenous bodies of vegetable origin contain far more carbon than do substances derived from animals.

In dissolved peaty matters the carbon may exceed the nitrogen six to twelve times. In sewage the ratio is entirely different, there being only twice as much carbon as nitrogen, and in very bad waters there may be three or four times as

Hence it was formerly contended that, when the ratio ɔon to nitrogen is large (C : N : 6 : 1), it is chiefly vege- matter that is indicated ; whereas if the ratio be low = 3 : 1, for example), pollution with substances of l origin has taken place.

ꞏeems unfortunate that the line of reasoning must at resent day be regarded as unreliable, for the Rivers ion Commission found that, when water holding much ıble matter, peaty acids, etc., is impounded, the high ɔf carbon to nitrogen gradually diminishes. Again, the ation of sewage through soil soon doubles or trebles the ve proportion of carbon to nitrogen. Hence, under well- d conditions, conditions ordinarily occurring, a water with vegetable impurity and a water polluted with sewage ꞏhow on analysis proportions of carbon and nitrogen very ꞏr to each other. Thus, the chemist cannot from the leration of the analytical results for carbon and nitrogen ɘ whether the contamination has been of vegetable or ꞏmal origin.

t a knowledge of the history of the water which is under ination may throw light on the problem in hand. One is ꞏ expect certain results from moorland streams, and some- quite different from deep wells and rivers. Well- ed divergencies from the analysis which is anticipated put the investigator on the alert. As in the case of ɔnia, it is certainly to be desired that the organic carbon ıitrogen together should be small in quantity—not more, ꞏding to Frankland, than 0·3 per 100,000 for moorland ɛs, and 0·1 for other sources. Small percentages of sewage ꞏaters escape detection by chemical analysis.* For ıple, good spring water adulterated with 1 per cent. of ge might only show 0·008 part of albuminoid ammonia, thus would arouse no suspicion. A bacteriological test d probably give more significant indication.

* Thresh, "Examination of Waters and Water-Supplies," p. 98.

CHAPTER XI

THE TESTING OF WATER—*Continued*

ELECTRICAL CONDUCTIVITY OF NATURAL WATERS, AND ITS APPLICATIONS.

A CONVENIENT and easily-applied mode of estimating the amount of dissolved salts in water is made to depend upon the resistance which a column of water of given length and cross-section offers to the passage of an electrical current. Pure water has very slight conductivity—that is to say, it offers high resistance. But when salts of lime, soda, etc., are dissolved in increasing amounts, the resistance decreases in a definite manner.* As a result of his experiments on test solutions with known quantities of commonly-occurring salts in solution, Kohlrausch has supplied a rule for deducing the amount of mineral matter in solution when the resistance is known. The apparatus for finding the resistance is of simple construction, and no technical knowledge is required for its manipulation. Self-registering instruments have been constructed to give a continuous record (exhibited by Pleissner at the Hygiene Congress in Berlin, 1907). Daily observations have been made at Paris since 1903 (*Revue d'Hygiène,* xxvi., 1904). The Berlin Institute for testing water and sewage has recently bestowed much attention upon this method.

The chief advantage is that warning is immediately given of any change in the quality of the raw water. For example, the intrusion of the overflow of river water into a deep well would cause a change in the electrical conductivity of the supply. Pollution by foreign matters, as sewage, effluents from factories, water pumped from mines, would also attract attention and lead to investigation. In short, if a record be

* This is true within limits not usually approached by ordinary waters. When a considerable amount of a salt is dissolved, the conductivity decreases.

kept of the daily observations, deviations from the normal act as danger-signals to the water manager. According to M. Imbeaux, who has fully discussed this method of testing water ("L'Alimentation en Eau Potable et l'Assainissement des Villes," Paris, 1902), "the process of electrical testing enables one to follow very simply the character of a water from day to day. It is both rapid and sensitive. It gives instant warning of the arrival of abnormal dissolved matters, and the contamination of a supply by sewage or other objectionable liquors—almost always accompanied by an elevation of the matters in solution—is betrayed by the increased conductivity of the raw water."

Not only the raw water, but also the filter effluents, the service water at various points, the water impounded in reservoirs, may be subjected to the conductivity test. A portable apparatus of convenient size has been constructed by Pleissner (see *Arbeiten aus dem Kaiserl. Gesundheitsamt* xxviii., 1908). Numerous interesting and useful records have been obtained by Chanoz in connection with supplies from the Rhone (*Lyon Medical Journal*, ci., 1905), by Prausnitz and Poda at the wells of the Gratz Waterworks (*Zeitschr. für Hygiene und Infektionskrankh.*, lix., 1908), and by the Königl. Versuchs-uh. Prüfungsanstalt in Berlin in relation to samples from different quarters.

Once the chemical analysis of a supply has been obtained, and the water found satisfactory, the weekly or monthly appeals to the analyst may be dispensed with, so far as concerns the inorganic ingredients. The electrical test is inexpensive, ready to hand, and only a few minutes are required to perform the experiment. True, the instrument does not indicate whether an increase of dissolved matters is due to the addition of harmful or harmless matters. But here, too, chemical analysis gives no manifest indication, unless the degree of pollution is gross. The electrical test would at once distinguish between distilled water and a mixture of this with 1 per cent. of sewage. Neither the chemical analysis nor the measure of electrical resistance would indicate whether the water was safe or the reverse. Bacteriological examination alone would furnish that information. This is frankly admitted by the advocates of the newer process (see Dr. Stoof's article in the *Gesundheits Ingenieur*, January 30, 1909).

Further, there is this to be said with regard to the inference which may justly be drawn from a decrease of resistance: Organic salts in solution and colloids are weak conductors of electricity, and the influx of considerable amounts of these would not greatly affect the resistance of the water. The probable presence of such matters would be revealed by the inorganic salts (chlorides, phosphates, sulphates) which almost invariably accompany them. The circumstance above mentioned appears to weigh with the directors of the Municipal Laboratory at Montsouris, for they publish weekly the organic analysis of the Paris supplies, as well as the electrical resistance and the bacterial content.

The Dionic Water-Tester.—This is an instrument designed to measure the conductivity of water. The sample to be tested is brought into a U-tube, which receives the electrodes of a hand-driven dynamo. The conductivity is indicated on a dial graduated to show very small differences, and the scale is adjusted to compensate for polarization. A table of corrections for temperature is supplied. The instrument is very sensitive, and the effect of adding from one-fourth to one-half of a grain of carbonate of lime per gallon is visible on the scale. The test can be completed in a few minutes.

Standards of Purity: Water-Supply of Paris.—1. No filter effluent shall be used unless it has been free from *B. coli* for five consecutive days.

2 The effluent of any filter which has let pass *B. coli* for two consecutive days shall be put out of service until it has again fulfilled the five-days condition of Regulation 1.

3. The *B. coli* test is to be made upon 40 cm^3. of the filtrate with phenol broth, and no turbidity should appear after twenty-four hours' incubation at 42° C.

Standards of Purity in America and Britain.—The table on p. 289 presents a comparative statement of the standards of chemical purity in Britain and America.

In general, the American authorities on water analysis adhere closely to the deductions from results accepted in Britain. The Massachusetts Board of Health has issued a Report in reference to this matter. A distinction is first drawn between "normal" waters which have not been contaminated with sewage, animal dejecta, and putrefying bodies, and those waters which are not exempt from such taint.

	British Waters should not exceed (Parts per Million)—	An American Local Standard should not exceed (Parts per Million)—	Average Analyses, Unpolluted Waters. Rain.	Upland Surface.	Deep Wells.	Springs.
Solids:						
Total residue ..	300 to 400	500	29·5	96·7	437·8	282
Inorganic residue ..	—	May constitute the total residue	—	—	—	—
Organic residue ..	Any is more or less objectionable	The less, the better the water	—	—	—	—
Chlorine (Cl). ($NaCl = Cl \times 1{\cdot}65$)	15 to 30 (except from known mineral sources)	6 (except from salt-producing districts)	2·2	11·3	51·1	24·9
Ammonia (NH_3):						
Free	0·05	0·05	0·35	0·025	0·122	0·012
Albuminoid	0·10	0·15	0·03	0·066	0·05	0·067
Oxidized Nitrogen (N):						
N as nitrates ..	1·5 to 2·0 (except from deep wells and springs)	0·90				
N as nitrites ..	Indication unfavourable	If more than trace, should not be regarded as safe	0·3	0·9	4·95	3·83
Oxygen consumed ..	3 to 4 (peaty waters excepted)	Should not reduce more than 8 parts potassium permanganate (*i.e.*, 2·02 parts)	—	—	—	—
Hardness:						
Total	300	—		54	250	185
Temporary	—	—	—	15	158	110

Now, since it happens occasionally that the free ammonia, the nitric nitrogen, and the albuminoid ammonia, in a normal water are higher than in some polluted waters, it is clear, says the Report, that chemical analyses may bring out results that do not carry their interpretation with them. A sufficient acquaintance with the locality from which the water is obtained should render the results intelligible.

In the case of ground waters, the opinion is hazarded that there is a possible standard of purity—namely, the entire absence of unoxidized or partly oxidized compounds of nitrogen. The nearer this ideal is attained, the stronger is the presumptive evidence that the supply is wholesome. Just in proportion as this high standard is departed from, so does the probability of the water being impure increase. The region of known danger has been entered. Not that one can assert that a water which reaches the ideal is for that reason alone to be looked on as unimpeachable. Accidental contamination is always possible.

Nor can one appoint a standard of purity for this class of waters based on the amount of nitric nitrogen. Deductions drawn from the determination of one ingredient are one-sided, and in general faulty. Besides, the content varies with seasonal changes, possibly also for reasons we may be ignorant of. Analyses should therefore be made at regular intervals. Instances are quoted of supplies which are bad all the year, save only for brief periods. The tests should, accordingly, be frequent.

Ground waters should be sought for as far away as possible from cesspools, rubbish-heaps, polluted streams and ditches and canals. Safety lies in being well removed from possible means of infection. A knowledge of the geology of the district is a *sine qua non*. In all cases bacterioscopic examination should accompany the chemical analysis, while the environment of the source must be carefully considered.

MICROSCOPIC EXAMINATION OF WATER.

Much may be learned regarding the condition of water from an examination with the ordinary student's microscope, and it is much to be desired that the use of this instrument were more general at waterworks. With a little practice, the observer is able to identify a great number of living and dead objects which occur in various kinds of supply water. Should

an intrusion of sewage have taken place, there would almost certainly be revealed some indications, as particles of different food-stuffs, starch granules, meat tissue, fibres of vegetable origin, and epithelium scales. Sewage also carries filaments of cotton, wool, hemp, of woody pulp used in paper-making, hairs, and many other things derived from the rubbish of the kitchen.

Surface and stream waters nourish a vast population of minute organisms, such as rotifers, diatoms, crustaceans, infusorians, water-mites, and all the diversity of forms now collected under the designation of "plankton."

Along the borders of streams, ponds, and reservoirs, is developed a rich variety of animalcula, which find among the water-plants and sediment a congenial harbourage, stocked with their natural food. Here we meet with beetles and their larvæ, gnats and other species of the same kind (Diptera), larvæ of caddis-flies, May-flies, dragon-flies, and stone-flies. Add to these various worms, mussels, snails, fresh-water polyps, and sponges. Anchored to the herbage in quiet waters are many beautiful forms, as the bell animalcula and other infusoria, fixed rotifers, and other lowly forms. Included in the plankton category are numerous plant species, notably algæ and other members of the cryptogamic family. The important rôle played by minute plants and animals in the formation of the filtering skin of the sand-beds should of itself commend the study of this branch of natural science to water managers and others interested in the purification of water.

Much useful information has been gathered recently with respect to the influence of living things on reservoirs and filters. Some forms are known to do good work in forming the slimy film ; others disturb it in the course of their development, and pierce it with tiny holes, which may at times account for unsatisfactory filtration results. The character of the filtering skin will depend much on the quality of the crude water, and supplies from lowland streams provide a richer variety of minute organisms than do upland waters. A rapid increase of plankton in the reservoir is to be dreaded, on account of the possible choking of the filters.

Plankton Net.—Timely warning is afforded by the use of the plankton net, an instrument simple both in construction and manipulation (Fig. 82). It consists of a conical bag of silk gauze attached above to a metal ring, some 2 feet in

diameter. Below, the pointed extremity of the net is secured to the mouth of a brass canister 4 inches wide, which is tapered to an outflow tube closed with a cock. This net is dragged at the end of a six-yard line behind a boat for five or ten minutes, as arranged, and with moderate speed. On being drawn in, the net is held above the water, so as to allow the liquid within to escape, while the plankton is retained in the brass canister. Sufficient water is retained to wash out the objects captured into a glass jar when the cock is opened.

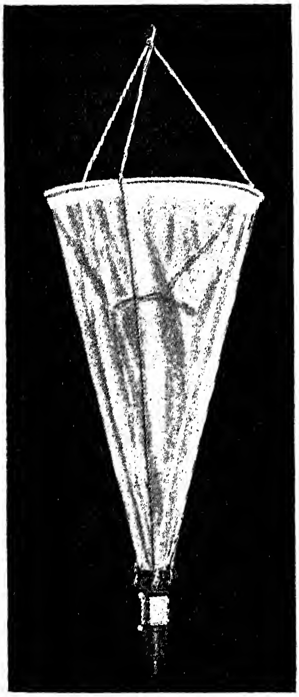


FIG. 82.—PLANKTON NET.

Deep-water plankton may be collected by permitting the net to sink vertically down to the required depth, and gradually raising it to the surface. If we desire to ascertain what forms exist at different depths at a particular time or season, then it is necessary to obtain a net which can be closed while yet it is below the surface. The simplest apparatus of this kind has a net affixed to hinged jaws. These jaws, when closed, can be opened by allowing a weight to run down the drag-line as soon as the apparatus has been sunk to the required depth. After hauling up a little, the net is shut by the fall of a second weight. The first of these weights releases a catch-spring, and allows the jaws to open out; the second presses them together once more.

After having collected a sufficient sample of the minute forms, one may proceed immediately to the examination of the catch with the microscope. A low power of fifty to seventy diameters is all that is required for the identification of the majority of the species. The watery fluid in the specimen jar is poured upon a filter of fine gauze, so that excess water may be drained off. The sediment can now be lifted upon a microscope slide with a wire loop, then moistened with a drop of water and brought into focus.

Should it be desired to preserve the sediment for future reference and examination, a simple process is to tie it up in the gauze and immerse it in a strong solution of corrosive sublimate for three hours. The gauze is withdrawn and the sediment within its folds is then transferred to a stoppered bottle containing 70 per cent. alcohol.

The natural orders which are represented among the constituents of plankton are numerous, and many different species are found, some preferring one habitat, some another ; some appearing here in profusion, and absent there, according to the character of the water, the climate, or the season. We can only illustrate some of the more generally occurring types that form the bulk of the plankton which abounds in freshwater ponds and reservoirs. For many of the diagrams, and for much of the descriptive matter, the authors are greatly indebted to Dr. Zacharias of Plön.

Crustacea.—To this order belong some beautiful species which occur almost universally in still waters, and often form a considerable percentage of the total plankton. In Fig. 83, *a*, is represented one of these, magnified about 25 times. A glance at its jointed limbs shows its affinity with the common crab and lobster, and within its minute body are structures of the kind one might expect among the Crustacea. These are readily visible under the microscope, for its tissues are perfectly transparent, and almost colourless, save for the greenish tint of its food-passage, which is represented by the dark central line in the figure. By means of its twin paddles, decked with feathery feelers, the creature pushes itself through the water, which offers slight resistance to its conical head. Popularly, animalcula of this type are called "water-fleas," from the fact that they advance by short jumps. The one shown here is a member of the Daphnia family, distinguished by the name of *Daphnia*. Another closely related and not less delicately beautiful animalculum is *Daphnella brachyura* (Fig. 84, *a*), with feather-like rowing arms. Its body is covered with a bivalve shell, within which are several pairs of limbs, which can be protruded when the valves open. As in the former species, there is but one eye, and the head is somewhat pointed or keel-shaped. Hundreds of these may be caught at one sweep of the net in the waters of inland lakes.

Closely allied to Daphnella in structure is the creature

Photo by] [*Messrs. Flatters, Milborne, and McKechnie.*

a, Daphnia, one of the Cladocera. (× 25.)

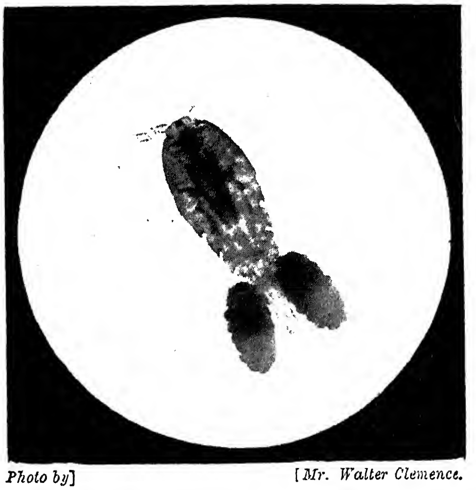


Photo by] [*Mr. Walter Clemence.*

b, Cyclops, one of the Copepods. (× 25.)

FIG. 83.—PLANKTON CRUSTACEA.

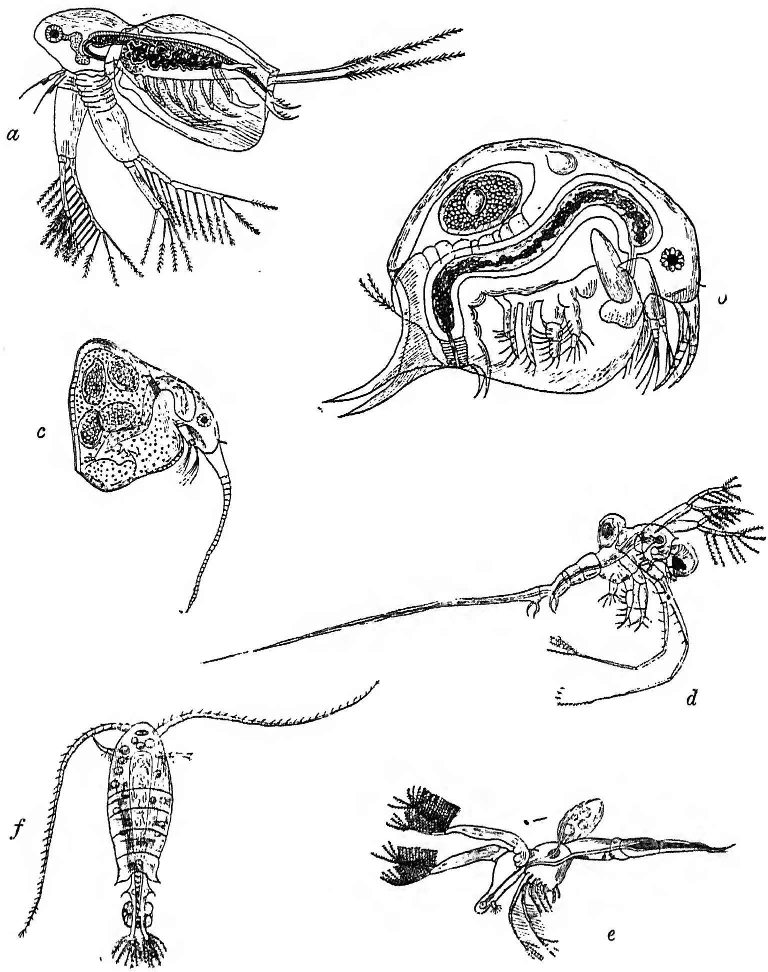


FIG. 84.—PLANKTON CRUSTACEA.

(After Dr. Zacharias, of Plön, by permission of Herr B. G. Teubner, Leipzig.)

a, Daphnella brachyura; *b*, Bosmina longispina; *c*, Bosmina gibbera; *d*, Bythotrephes longimanus; *e*, Leptodora hyalina; *f*, Diaptomus, one of the Copepods.

Approximate Magnification: *a*, *f*, × 20; *b*, × 50; *c*, *d*, × 15; *e*, × 5.

represented in Fig. 84, *b*, which is easily recognizable by two hornlike projections from its posterior end, which, with its pair of jointed probosces in front of its bulky body, remind one of an elephant in miniature. This is *Bosmina longispina.*

It is to be noted that the females of these lowly crustaceans have a special cavity placed well back in the body, in which the ova are retained until they are able to take care of themselves in the water. Such a cavity, with its contents, is well seen in the last type, and also in the diagram of *Bosmina gibbera* (Fig. 84, *c*), which abounds in the lakes and ponds of West Prussia.

Much the largest of the crab family included among plankton is *Leptodora hyalina* (Fig. 84, *e*), which is a constant habitant of lakes. It may attain a length of ½ inch, and, being quite transparent, its delicate structure can be admired under low magnification. With a higher power of the microscope its wonderfully beautiful eye may be seen, beset with numerous crystalline bodies. The quick-pulsating heart can be distinguished in the middle region. Behind and above the heart the egg cavity is seen in the figure. The locomotive apparatus is placed in front, and consists of a pair of elegant arms. Very large specimens of Leptodora are frequent in the Canadian lakes.

As an example of deep-swimming Crustacea, we add the interesting type pictured in Fig. 84, *d*, which was discovered by Professor Leydig when seeking information regarding the food of certain fishes in the Boden See, which rarely come near the surface. He was surprised to find little in the alimentary canal save minute crustaceans with very long spine in rear, two powerful swimming arms in front, and the first pair of swimming legs of unusual size. He named his discovery *Bythotrephes longimanus*, the " deep-sea food."

The species already described all belong to the order of Cladocera, distinguished by their branched antennæ ; and there are many more allied forms. In addition, another great family of the Crustacea is fully represented in lacustrine plankton. This is the Copepoda, which naturally falls into three divisions ; but all the members are characterized by a jointed body, with broad plate in the head and thorax region, and a forked tail. For swimming they are provided with two long feelers bedecked with bristles.

We select types of two of the divisions of copepods, the

ird not falling within our province. Few microscopic imalcula present a more singular appearance than *Cyclops* ig. 83, *b*), with its large solitary eye, spheroidal body, and uble tail. Here the egg cavity is quite distinct from the dy proper, and consists of two rounded sacs projecting one each side of the tail. The bristly antennæ are much orter than in the next type.

Diaptomus (Fig. 84, *f*) belongs to a family of more than sixty embers, all formed on similar lines, with long, bristle-covered immarets, segmented body, branched tail, and posterior gg sacs. The number of segments may reach twenty-five this family. It is well known that Diaptomus and many her small copepods feed upon diatoms—particularly on Cyclo-lla—and portions of this favourite food may be observed in e transparent alimentary canal. On the other hand, the aphnias and Bosminas (Fig. 84, *a*, *b*, *c*) live on algæ and ecaying vegetable substances forming the slimy mud of pools. he dark outline of the food-tube already referred to (p. 293) due to the nature of their provender. Diatoms form a much ore nutritious food than one would have anticipated, for e analysis of their bodies shows 29 per cent. albumin, 3 per cent. carbohydrates, and 8 per cent. fatty matter. ccording to Dr. Zacharias of Plön the copepods would seem be almost the only creatures which take advantage of this cellent nourishment. Their young larvæ—the Nauplias—re, however, vegetable feeders.

Crustaceans form an important part of the nourishment of shes, and it is a common practice in Germany to "manure" e fishponds with the dejecta of animals, so as to encourage e rapid development of these minute creatures. A distinct dvance in the scientific practice of rearing fresh-water fish r human consumption was thus established, and chiefly rough the work of Dr. Susta, the so-called reformer of the arp industry in Bohemia.

Behaviour of Plankton Crustaceans in Regard to Light.—It as been demonstrated that during the bright sunshine of the mmer months the surface waters of the Swiss and Italian kes are absolutely deserted by the copepods. Dr. Zacharias und none within a depth of 100 feet at three o'clock p.m. of a nny day in the Lake of Geneva, and in the Italian lakes no

plankton crustaceans at all under like conditions until the net was put down 80 feet. In the lakes of North Germany he also discovered that the crustaceans had removed to a depth of 18 to 24 feet when the sunlight was strong. That they do not go deeper he thinks is due to the fact that the northern lakes are less transparent, owing to abundance of surface algæ.

When the day begins to decline, there sets in a migration of the crustaceans towards the surface. This has now been carefully studied by many observers. Dr. Zacharias, after an extended course of investigations, came to the following conclusions : Commencing with sundown, when the Crustacea begin to arrive at the top of the water, the numbers increase as the light fails, till a maximum is reached about ten to eleven o'clock. This condition remains for hours, on to about 3 a.m., when the descent to deeper waters is in evidence. This proceeds up to 6 a.m., when the movement seems to be complete. A few of the copepods wander back to the surface during the next three hours—not, however, more than 5 per cent. of the whole.

Dr. Burckhardt finds that the depth to which the Crustacea sink is proportional to the intensity of the sunlight. In dull, cloudy weather there is very little migration. There is less, too, during the winter, when the sun's rays are more oblique. The copepods are much more sensitive to light than are the Daphnias (Fig. 84, *a*) and Bosminas (Fig. 84, *b*, *c*), though the latter also undertake a more limited migration. The larvæ of the copepods, Napulias, do not migrate.

By many naturalists it is believed that these daily movements have to do with the search for food. Crustacea are voracious feeders, and were they to remain far down by night, they would be unable to continue the pursuit of their prey, as the darkness would be too intense. Did they remain exposed to the strong light of the noonday sun, their organs of sight would be incapacitated from discerning minute objects in the comparative obscurity of night. Being a most prolific race, they have need to be eating constantly. Their eyes are adapted to detect minute particles of food more readily in a dim light, and therein lies the explanation of their migration.

With regard to the geographical distribution of crustaceans occurring in fresh-water plankton, it has been shown by Dr. Eckman (*Zool. Jahrbuch*, xxi., 1904) that many species

ın Swedish waters can live equally well in the cold lakes ııgh up among the mountains and in the more tem- waters of the lowlands. A few types are characteristic highland lochs, and others are exclusively denizens of d ponds. Similar conditions in mid-European countries ı like influence on the crustaceans. Dr. Zschokke of onsiders that those forms truly characteristic of the waters are survivals of the Ice Age. They are in- nts alike of the Alpine lakes nearest to the snow- nd of the lochs in the Far North, whose waters are ntly at a low temperature.

fers.—Plankton rotifers are a distinctly microscopic , for the average length is not more than $\frac{1}{50}$ inch in se of the females, and the males are smaller still. They heir name from the possession of a disc embraced by a of fine, threadlike cilia, which oscillate with great y, and give the false impression that the whole disc is ıg. The build of disc and the ciliary appendages vary erably in the different species, but the broad characters order are alike in all. The diagram (Fig. 85, *a*) given of *ıchna periodonta* shows the creature to be an elongated ith wide mouth, enclosed in a circlet of cilia. These the animal to move through the water, and they sweep es of food into the mouth. Inside the mouth are masti- teeth, which are in continual motion. Farther down egg s are visible, while near the constriction below the mouth rtain red spots, which are commonly classed as eyes.

next two species represented (Fig. 85, *b*, *c*) are frequent tants of fresh-water ponds. In both the cilia are ed in bunches. *Polyartha* is furnished with leaflike dages, which greatly aid its progress in the water and ıuch to its beauty. The egg sac is placed right in rear, large (comparatively speaking) oil-drop may be seen em- d among the ova. The length of this comely organism end to end is not more than $\frac{1}{150}$ inch. Hardly larger is *ha longiseta* (Fig. 85, *d*), with its twin rowing bristles and tail. Another type of this kind found in North German has its rowing arms five or six times longer than the

add diagrams of two species of rotifers which are pro-

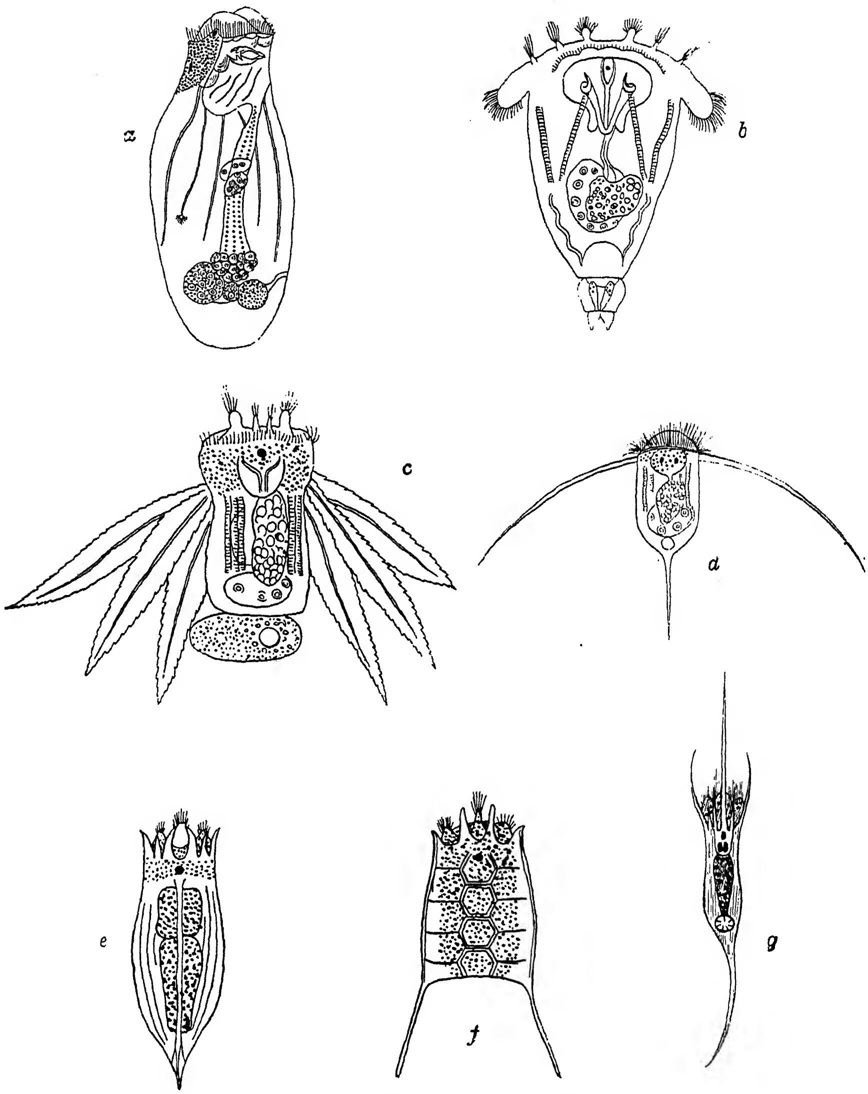


FIG. 85.—PLANKTON ROTIFERS.

(After Dr. Zacharias, of Plön, by permission of Herr B. G. Teubner, Leipzig.)

a, Asplanchna periodonta ; *b*, Synchœta pectinata ; *c*, Polyartha platyptera ; *d*, Triartha longiseta ; *e*, Notholca acuminata ; *f*, Anurœa aculeata ; *g*, Notholca longispina.

Approximate Magnification : *a, g,* × 50 : *b, d,* × 100 ; *c, e, f,* × 200.

vided with breastplates variously designed (Fig. 85, *e*, *f*). Finally, the very commonly occurring *Notholca longispina*, which has a three-sided body, is represented in Fig. 85, *g*.

It has often been a matter of surprise that pools of water which collect in hollows after wet weather are very soon tenanted by abundant plankton. Doubtless many species are conveyed from pond to pond by birds on their damp limbs and plumage. If food be abundant, the multiplication is extremely rapid, a single Daphnia being capable of producing hundreds of millions in the course of a couple of months. The Daphnia family seem to make provision purposely for the distribution of their kind, for they are able to seal up packets of eggs and detach them from their bodies in floating capsules, which collect around the borders of ponds, become mixed up with the muddy sediment, and thus cling to whatever comes in the way.

Plankton Flagellata.—Not far removed from the borders of the vegetable kingdom are the whip-bearing animalcula which in summer swarm in the surface waters of stagnant waters. In some cases the myriads of *Dinobryon sociale* (Fig. 86, *a*) give a yellow tint to the surface waters. The individuals of this class group themselves into colonies of fifty or more. They are minute, and form part of the food of rotifers. Equally abundant is the shapely creature represented in Fig. 86, *b*, which under the microscope is seen to be protected by an outer coating of cellulose plates knit together. In the hot months of the year the surface waters of ponds are sometimes quite turbid with swarms of different species of Ceratium. It was noticed by Dr. Zacharias at Plön that they change in shape to some extent with the season. Many other animalcula vary in configuration with the change from a hot season to cold.

A constant inhabitant of lacustrine waters in summer is *Uroglena volvox* (Fig. 86, *c*), which is a spherical aggregation of hundreds of tiny pear-shaped animalcula. These are set in a matrix of a gelatinous substance or jelly, and the individuals of the system are anchored to fine threads, which radiate from the middle point of the ball. Movement is effected by means of the flagellum which each animalcula bears, and the ball advances by a sort of rolling motion. Under moderately high power of the microscope Uroglena is an object of

great splendour, owing to the fact that each of its many colonists is adorned with two golden-yellow plates and a deep red eye-spot.

Allied to it is *Synura uvella* (Fig. 86, *d*), which is very frequent

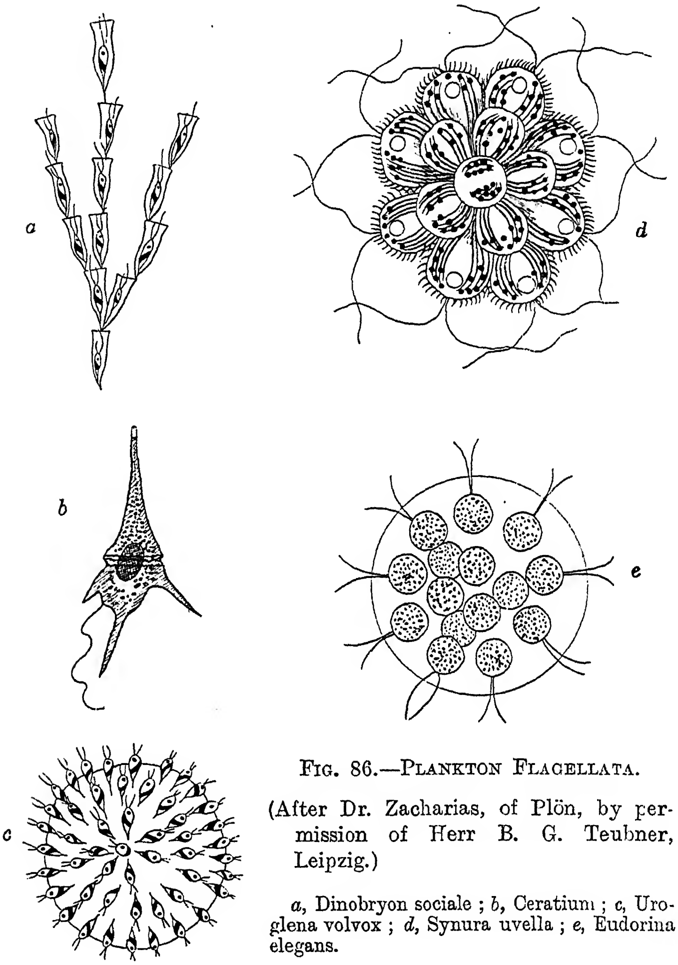


FIG. 86.—PLANKTON FLAGELLATA.

(After Dr. Zacharias, of Plön, by permission of Herr B. G. Teubner, Leipzig.)

a, Dinobryon sociale ; *b*, Ceratium ; *c*, Uroglena volvox ; *d*, Synura uvella ; *e*, Eudorina elegans.

Approximate Magnification : *a*, *d*, × 400 ; *b*, *c*, × 125 ; *e*, × 250.

in peaty pools. The units which form the spherical colony have two flagella, and are bedecked with short bristles.

In the earlier months of the year *Eudorina elegans* (Fig. 86, *e*) is found in abundance in fresh-water lakes.

The foregoing must be regarded as mere samples of the very rich and diversified order of Flagellata. From Dr. Zacharias we learn that these elegant animalcula increase at times to such an enormous extent that they colour the surface waters to a marked degree. Amid the myriad life existing there, one may often find *Volvox globator* (Fig. 86A), the well-known microscopic object. Dr. Zacharias counted as many as 680 specimens of this and closely allied types in one litre of pond water during the heat of a summer day. Contrary to the practice of the plankton Crustacea, these Flagellata people the surface waters by day, and sink down into deeper levels by night. The

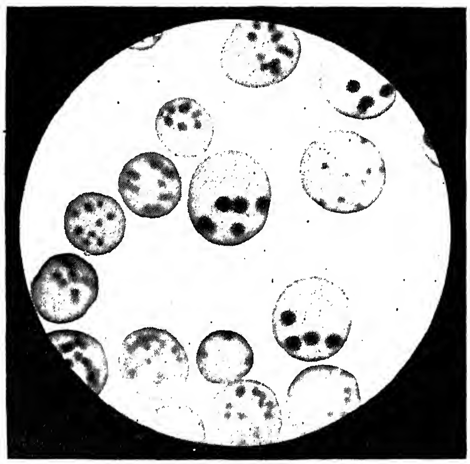


Photo by] [*Mr. Walter Clemence.*

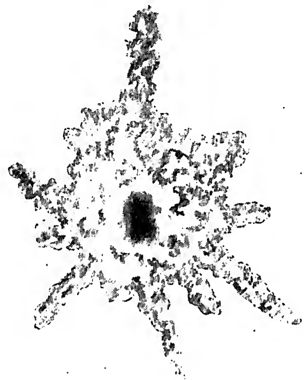
FIG. 86A.—PLANKTON FLAGELLATA.

Volvox globator. (× 20.)

migration is, however, less complete in this case, for a certain percentage—namely, the young and immature individuals——remain swimming near the surface all night.

Plankton Rhizopods.—The lowest forms of life are to be found among fresh-water plankton, and of these we notice a few types which are at times abundant. The rhizopods are minute creatures of very primitive build, tiny specks of a jelly-like protoplasm, which have the power of throwing out fine threads, partly for the purpose of locomotion, partly in order to capture food. The ladder of animal existence begins with the tiny drop of protoplasm, *Amœba* (Fig. 87, *a*), which differs

but little from a white blood-corpuscle. It occurs in quie ponds, and a near relative, the *Chrysamœba,* possessing flagellum, is often brought in in great numbers by the plankto net in summer-time. Slightly higher in the scale of life ar the "shell"-bearing rhizopods, of which *Difflugia* (Fig. 87, *b* is a well-known example. This species often appears in swarm



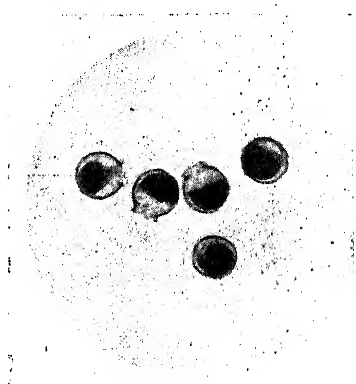
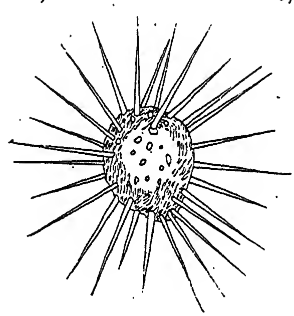


Photo by] [*Messrs. Flatters, Milborne, and McKechn*

a, Amœba. (× 500.) *b,* Difflugia. (× 100.)



c, Actinophrys sol. (× 500.)

FIG. 87.—PLANKTON RHIZOPODS.

almost without notice, and after a few days begins to disappear rapidly. Minute though Difflugia is—often not more than $\frac{1}{500}$ inch—its "shell" is finely constructed from the minutest particles of grit and sand, cemented together by a secretion which exudes from its own substance. Within the covering is an air-space, which seems to act as a swimming bladder, so that the animal can rise or sink at will.

More symmetrical in build than Amœba is *Actinophyrs sol* which is a minute sphere of about $\frac{1}{1000}$ inch in diameter, with radiating filaments (Fig. 87, *c*). These it has the power of retracting, and when this happens the creature is easily mistaken for an Amœba. There is a process of feeding, during which the filaments seize the food particle, and gradually drag it inside through the soft wall, which then closes up. Indigestible or fæcal matters are ejected. New individuals are produced by budding or by conjugation of two mature cells, whereby the offspring is obtained.

Very many other species of this order are met with in fresh water, and for these the reader is referred to the special literature of this subject (see Bibliography, p. 358).

Plankton Diatoms.—Hitherto we have dealt with species which are either members of the animal creation or close to the boundary line which divides off the vegetable kingdom. We now pass to the consideration of forms which are unmistakably to be referred to the domain of plants. All the plankton species which concern us are commonly included in the three divisions of algæ—to wit, the green algæ, the blue algæ, and the diatoms, or rod algæ.

The last group plays a very important rôle in the filtration of water in the absence of the others—that is to say, in winter, when green and blue algæ are sparingly developed or entirely absent. The individual diatom is of peculiar structure, entirely exceptional of its kind in the vegetable world. It is enclosed in a siliceous capsule consisting of two portions corresponding to a box and lid, these two parts being of equal size. The symmetrical thickenings of the capsule, together with the brown or golden-yellow particles within, give to these minute objects an appearance of wonderful beauty under the microscope.

The best-known species is *Asterionella gracillima* (Fig. 88, *a*), which is star-shaped, with six or eight rays, each thickened and rounded at the extremity. Dr. Voigt, of the Plön Laboratory, discovered that the rays of Asterionella and its allied forms act as ribs for the support of a fine membrane which greatly assists these diatoms to float. In Fig. 88, *b*, is shown a star-shaped diatom which frequents ponds and lakes during the summer. In the Lake of Zurich it is at times the most abundant plankton species present.

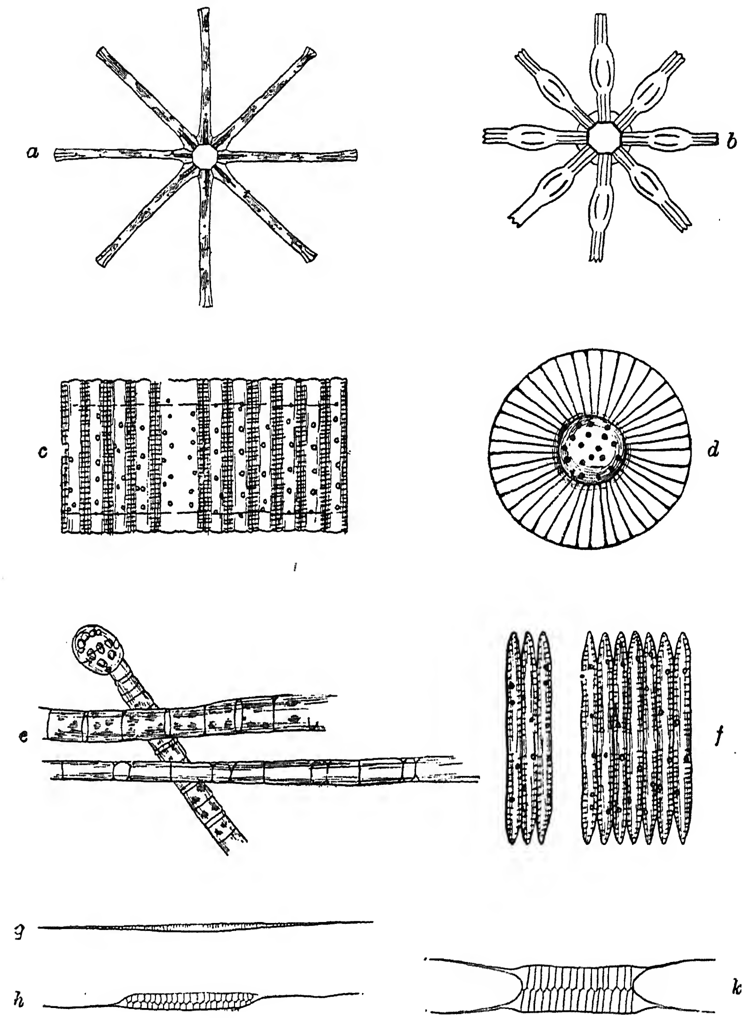


FIG. 88.—PLANKTON DIATOMS.

(*b*, *d*, *g*, *h*, *k*, after Dr. Zacharias, of Plön, by permission of Herr B. G. Teubner, Leipzig.)

a, Asterionella gracillima; *b*, Tabellaria asterionelloides; *c*, Fragilaria; *d*, Cyclotella radiosa; *e*, Melosira granulata; *f*, Synedra pulchella; *g*, Synedra delicatissima; *h*, Rhizosolenia longiseta; *k*, Attheya Zachariasi.

Approximate magnification: *a*, *b*, *e*, *h* × 400; *c*, *d*, *f* × 500; *g*, *k* × 250.

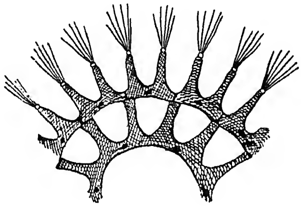
Quite differently built are the comb algæ, which are composed of a hundred or more individuals, all somewhat spindle-shaped, attached to each other by their middle parts, so as to form a long band. The projecting extremities give the semblance of a double comb. The type represented in Fig. 88, *c*, is the common *Fragilaria*. The members of this aggregate are held together by an adhesive secretion from the body wall. The comb algæ are usually flat, but there are forms which are twisted about the long axis into a spiral of one half-turn. *Synedra pulchella* (Fig. 88, *f*) is built up in the same way as *Fragilaria*.

Rarely absent among the plankton are the disk algæ, of which *Cyclotella radiosa* (Fig. 88, *d*) is typical. It is a double box, not more than $\frac{1}{500}$ inch broad, the twin capsules being prettily marked with radial lines diverging from a dotted centre-piece. There are numerous similar forms. *Melosira* (Fig. 88, *e*) is a threadlike diatomaceous growth, with the tubular individuals adhering by their flat ends. This grouping together of minute entities into plates and threads has evidently the purpose of increasing buoyancy. To sink into the depths would probably be fatal. For this reason, possibly, forms are assumed like *Synedra delicatissima*, with its elongated extremities; *Rhizosolenia longiseta*, with two bristles; and *Attheya*, with four (Fig. 88, *g*, *h*, *k*). In the two last the fine dentate junctions of the siliceous plates are especially noticeable.

Plankton Algæ.—There are few species of floating, free-moving algæ, and as the commonest type of the green variety we may name *Pediastrum duplex* (Fig. 89, *a*), which is a microscopic object of rare beauty. The sprays of bristles give assistance in floating. A like service is rendered to *Scenedesmus quadricauda* by the hornlike extensions from the terminal cells (Fig. 89, *b*).

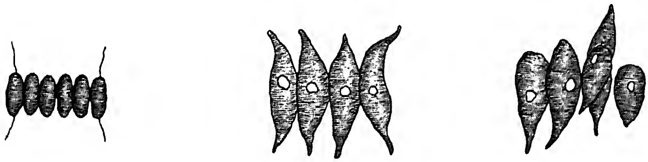
More deserving of notice are the floating blue algæ, which at times increase with such rapidity that they impart to the surface waters a distinct colouring, which in Germany goes by the name of *Wasserblüte*, or "water-blossom." The "blossom" lasts but a few days, and it is occasioned by the sudden uprising of multitudes of blue algæ from moderate depths. The increased buoyancy which certain cavities dis-

tended with gas confers upon them enables these forms to mount to the top of the water. The best known is *Anabæna* (Fig. 12), which consists of long, beadlike threads, sometimes fairly straight, sometimes spirally turned. These blue algæ are responsible for nauseating odours, and this is especially true of an allied form, which has caused trouble in European countries and in America, as at the Boston Waterworks.



a, Pediastrum duplex. (×500.)

(After Dr. Zacharias, of Plön, by permission of Herr B. G. Teubner, Leipzig.)



b *c* *d*

b, Scenedesmus quadricauda (×500); *c*, *d*, the same, more enlarged to show mode of development.

FIG. 89.—PLANKTON ALGÆ.

Periodicity of Plankton Species.—Reference has already been made to the circumstance that some kinds of plankton appear in abundance for a brief time only, and then rapidly fall away in numbers. In a broad sense we may distinguish between winter and summer plankton, and there are more restricted groups which are characteristic of spring and autumn. Copepods, for example, reach their maximum growth in October to November, generally overtopping all other kinds in these months. Again, in springtime the species most in evidence are *Eudorina* (Fig. 86, *e*), diatoms, as *Fragilaria*, *Asterionella*, *Synedra*, and certain infusoria. Plankton Crustacea and many rotifers come to their maximum development in the months of July to September. *Melosira* (Fig. 88, *e*

is a feature of the surface waters in winter, increasing gradually in numbers from December on to April, and then diminishing. Dr. Zacharias found several thousands of Melosira threads per litre of the Plöner See in the winter of 1904-05. He also observed the gradual increase in the number of the species Asterionella, from 50 per litre on March 1 to 1,800 on the 20th, and still advancing to 5,000 on April 1, and 9,000 on the 20th. There was a decrease after this for a fortnight, and then a marked increase of 8,000 in three or four days. The falling off was due to a short spell of cold weather. He also counted the Fragilaria present, and deduced that a rapid increase takes place between May and July. For every individual of this kind at the beginning of May there are at least a hundred ten weeks later.

Dr. Zacharias calculated that at a time of abundant development the total weight of Melosira per acre of the Plöner See would amount to five or six tons. How vast, then, must be the number of individuals, when it is remembered that each is but $\frac{1}{25}$ inch long and $\frac{1}{1000}$ inch thick!

Of course, the fertility of plankton in different lakes varies much, some waters being well suited to the growth of these minute forms, while at other places the growth is scanty. In general, shallow pools are more favourable than deep ones to the multiplication of the various species. The longer the banks are in proportion to the area of the water, the more productive is the water of plankton. The addition of sewage and the drainage of farmyards is favourable. Scarcity of organic food is, no doubt, one of the causes of the thin crop of plankton in elevated lakes.

It is peculiar that several species which disappear from large sheets of water at the commencement of the cold season persist during the winter in small ponds. This is the case with *Asterionella gracillima*, *Synedra delicatissima*, *Fragilaria crotonensis*, and *Diatoma tenue*, not to mention others. To what circumstance this is to be attributed it is difficult to conjecture; evidently the influence of temperature must be a secondary consideration. There is a readier access to food and shelter in small ponds. Light plays a more important rôle than temperature, for during the first months of the year the temperature of lacustrine waters does not vary greatly, and yet about March the plankton flora begins to increase with

rapidity. Dr. Zacharias found the Asterionellas and Fragilarias much more abundant in that month than in December, though the water was quite as cold. The sunlight was, however, very different in March, and more favourable to the physiological actions which belong to plant life. The mutual dependence of plant and animal species in the cycle of life has to do with the rate at which the development of plankton may go on, an abundance of animal forms being favourable to the appearance of a rich flora, and *vice versa*. In this way all the other living things in the water, whether swimming or attached to the banks and bottom, have intimate relations with the growth and permanence of microscopic species. Insect larvæ, infusoria, beetles, water-snails, worms, and many other creatures, harbour about the weeds around the borders of ponds. By their vital actions while alive, and by their decay when they die, they import into the water the materials on which plankton is nourished. The dejecta of fishes and water-fowl is a further source of food. Conversely, the higher forms feed upon the lower, and the fertility of one order in the scale of life in general helps the productiveness of another. By preventing the growth of weeds and the deposit of mud along shallow borders, a restraint is placed on the multiplication of all species, free or fixed. But many waters which are impounded for public supply carry with them quantities of impurities which can easily raise a crop of plankton. Surface drainage and river water, especially that taken from the lower reaches, soon become peopled with living things when collected in a reservoir. The natural purification which goes on during storage is to a greater or less extent the work of plankton. The organic substances are absorbed; the carbohydrates change in the living organisms to carbonic acid gas and water; nitrogenous bodies yield urea, which readily breaks up if freely exposed; and ammonia and its compounds are taken in by plant species.

CHAPTER XII

THE PROBLEMS OF DISTRIBUTION

THE conveyance of clear water from the reservoirs to the area of distribution is a matter which specially engages the attention of the engineer. He must take care that the water is led to its destination without waste by leakage, and, as far as possible, without deterioration of quality. He has therefore to decide upon the most suitable material for the main pipe, the securest form of joints, and the method of connecting the main with the reservoir at one end and the network of distribution at the other.

Cast-iron pipes, steel pipes, and conduits of reinforced concrete, are in everyday use, and aqueducts built of masonry occur at different places. Steel pipes are light and strong, but they are objected to by some engineers on account of the thinness of their walls, which would rapidly yield if corrosion set in (Transactions of Water Engineers, 1909, p. 213). Steel pipes are delivered in longer sections, which reduces the number of joints to be formed. They are cheaper to the extent of about three shillings per yard for an 8-inch pipe. Thinner by far in the walls than cast-iron mains, they yet possess great tensile strength, and may be employed, at least, wherever burst pipes would occasion much damage to property. Both kinds of pipes must be protected from corrosion as far as may be, and the best method now in vogue is to coat them with Dr. Angus Smith's preparation (see p. 317). Steel pipes are further guarded by a jacketing of jute cloth, which preserves the external coating, and acts as an insulator from electric currents.

Aqueducts of masonry require to be maintained water-tight, more especially when passing through districts in which surface water finds lodgment. In the vicinity of habitations,

drains, polluted streams, manured fields, and all gatherings of decaying matter, no pains should be spared to see that the structure is sound. There is sometimes a considerable suction in the main when the water is drawn off more quickly than usual. This would be felt distinctly if the inlet is contracted or clogged, for a sudden demand, drawing away more water than can enter at the same time, leaves a partial vacuum within. Should there happen to be any crevices in the walls, fluids on the outside are sucked into the interior. Recently the defective condition of an aqueduct was detected by the complaints of consumers that the water tasted of paraffin. An examination of the track showed that a leaky paraffin cask stood near the line of the main, and further investigations brought a faulty state of the walls to light.

The application of reinforced concrete to the construction of water mains and aqueducts has found favour abroad, and it has been adopted at Clydebank, Loch Braden, and other places in Britain. The concrete pipe is cast in sections in an iron mould, and is strengthened by a close spiral of iron wire embedded in the matrix of concrete.

Joints in Mains.—Joints in iron and steel pipes are commonly made with yarn and molten lead, and certain authorities prefer to use cold lead rings without any vegetable fibre. The latter substance is known to decay and foul the water to some extent (Transactions of the Association of Water Engineers, 1901, p. 39). In Paris the pipe sections are without flange, socket, or bead. They are laid end to end, the very small interval between contiguous ends is covered up with a fillet of clay, and a flat annulus or collar is put in position to cover the joint. It is held by wedges while the lead is poured in, and a very serviceable connection is thus made. The annular collar is cast with a slight taper, so that it can be knocked off if the pipe requires to be disconnected.

Carrying Capacity of Mains.—What the diameter of the main should be must be gauged from the actual demand, from the probable increase anticipated during the next generation or longer, as it may be resolved, and, lastly, from consideration of the very possible loss of carrying power owing to internal corrosion. Provision may have to be made for increasing the delivery in case of emergency—as, for example, an outbreak

of fire. The maximum discharge from the town end of the main having been determined, water-pipe discharge tables furnish particulars as to the dimensions necessary with various gradients (see p. 352).

Air in Mains; Scour Valves.—When the water main is put in service, it is found that air tends to gather at the highest points of ascending curves in the route, and, as the carrying power of the pipe is thus decreased, it is advisable to fit air-valves at these points. At the lowest points of descending curves it is customary to introduce scour valves, so that the main can be cleaned when desirable. Experience shows that this operation should be done regularly. The interval between scourings will depend on the nature of the supply, but it is imprudent to allow débris to accumulate.

The discharge from a scour in country districts is generally led to the nearest stream, with or without the interposition of a sedimentation tank, as may be arranged. In towns the sewers are made to receive the outflow, and it is very needful to see that the capacity of the drain is adequate for the reception of the volume of water which is discharged into it. Should the discharge fill up the drain and cause the water to stand back, the pressure behind the outflow will not prevent the ingress of diluted sewage by the back-currents which are set up. The explanation is that, if the drain is unable to carry off the water as fast as it is poured in, the pressure therein becomes equal to that within the pipe, and the reflex current is therefore able to enter the water main. Cases are on record in which this has occurred.

At some waterworks—*e.g.*, Moscow—the leading main and its branches are protected from hammer by a series of concussion valves (p. 339).

Connections with Reservoir.—The connection from a large storage reservoir is mostly effected in the following manner: A culvert of sufficient size is formed under the embankment, usually at the lowest point. It is located in a trench which has been excavated down to a solid foundation—rock or clay if possible. From the bottom of the trench a base of concrete or masonry is brought up to the level at which the pipe is to rest, and the arch of the culvert encloses the water main, and protects it from the pressure of the overlying embankment.

This method is much to be preferred to the plan of bedding the pipe in concrete, and wrapping it above with the same material, as any defect can be quickly detected and repaired. The discharge pipe passes inside the embankment to a valve tower, which carries a platform from which the valves are operated. There must, of course, be provision for drawing off the water at different levels.

The outlet from the service reservoir to the main is furnished with a rose or screen of copper or brass wire netting. In small waterworks a rose is generally provided, but for larger deliveries there is often affixed to the outlet a frame with two or more grooves for receiving screens. When it becomes necessary to clean away adherent algæ or other matter intercepted, a fresh screen is inserted in rear before the other is raised. During certain seasons these screens are apt to become choked with animalcula, algæ, etc., in uncovered basins. They must therefore be examined at regular intervals.

Distribution within the Area of Supply.—Passing on to the distribution of the water to the district which is to receive the supply, it will be evident that the engineer must take into account the contour of the area, the manner in which the population is dispersed, the contingency of a large demand for fire extinction in any particular quarter, special requirements of industrial concerns, and other matters.

In many cases water is collected and stored at a distance from the area which it is intended to supply. Pipes convey the water to a convenient station in the vicinity of the distribution area. There it may be further purified and brought into a service reservoir of one or two days' capacity. The site of such a reservoir should, if possible, be so chosen that the clear water can be distributed by gravitation. In a level country, pumping has in general to be resorted to.

The method of distribution that naturally suggests itself in a level district is to run the principal main through the centre of the area, and lead off branches to right and left along the chief routes. Side-branches complete the distribution. To this system there is the objection that dead ends are almost inevitable. There the water stagnates and becomes fouled with the gatherings of sediment. Living things are often found harbouring in a cul-de-sac, as larvæ of Chironomus,

crustaceans, etc. It is very necessary that dead ends should be avoided. This may be effected, in case the distribution is planned in the way stated, by connecting the ends of one branch to those of the next.

When this is done, the arrangement corresponds pretty closely to the so-called "gridiron system," in which the pipes cross and recross like the strands of a herring-net. The advantage is that, if there be a great demand at any point, there is sure to be an ample supply poured in from the surrounding district. The disadvantage is that, in order to isolate a particular locality, it is necessary to close a large number of valves all round it. The difficulty can be only of occasional occurrence, and the extra labour is more than counterbalanced by the good which results from keeping the water in the pipes in circulation. The whole network being linked together, the drawing off of supply at any one point sets the contents of all the pipes in the neighbourhood in motion. There are no dead ends.

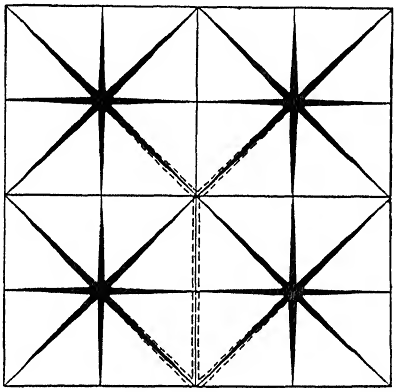


FIG. 90.—DIAGRAMMATIC SCHEME FOR DISTRIBUTION.

An alternative is to divide the main at one side of a district, and carry the two portions right round the area till they meet on the farther side. Cross-branches connect points on the periphery at suitable intervals, so as to form a net within the loop. Thus an exceptional demand at any spot draws in water from the whole area circumscribed. As the transverse pipes are nourished from both ends, they do not require to be so large as in the other case. Sluice valves must be placed at all crossings, in order that repairs, burst pipes, replacements, etc., may be conveniently dealt with.

If it be proposed to distribute the water by means of radiating mains, it will in general be found advantageous to have two or more centres, as the radial arms are shortened and the free ends can be connected up (Fig. 90). Wherever dead ends do

occur, they must be provided with scour valves, which are to be regularly used.

Fire Hydrants.—Water undertakers are required to provide fire hydrants at certain points when called upon to do so by the Local or Municipal Authorities, and it is important that a good type of hydrant should be adopted. The ball hydrant (Fig. 91) is not altogether free from objection, and complaints have been heard against it. The hydrant box is a receptacle in which surface water and street rubbish may easily collect. Nothing can enter the main so long as there is pressure sufficient

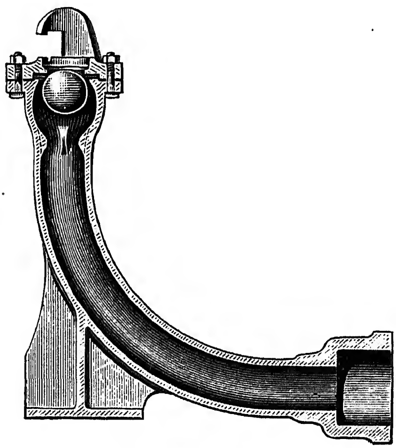


FIG. 91.—BALL HYDRANT.

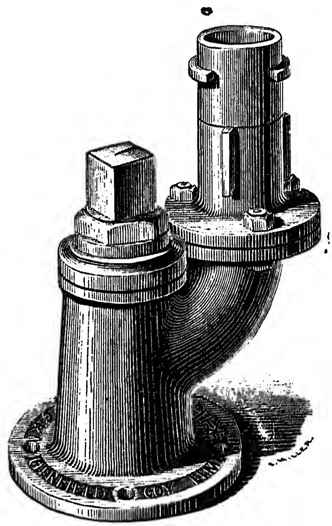


FIG. 92.—GLENFIELD AND KENNEDY'S FIRE HYDRANT.

to keep the ball in position. But as soon as this slackens owing to excessive demand, or to the pipe being emptied for repairs, the ball drops, with the result that the dirty fluid in the box above is drawn inside, causing gross pollution for a time.

The valve hydrant shown in Fig. 92 obviates any risk of this nature. There are various improved designs now on the market.

Lead Pipes for Connections.—The branch pipes from the mains to consumers' houses are mostly of lead, this being a very suitable metal from the workman's point of view, as

connections can be made with little trouble. Lead pipes are easily bent, and, except with plumbo-solvent or plumbo-erosive waters, they have a long life. They do not corrode as small iron pipes would do, either internally or externally. Copper pipes are expensive; otherwise there would be many advantages in using that metal. Copper seems to have bactericidal properties, and it has been recommended as a lining for cisterns. Lead pipes lined with tin have been tried as a preventive of plumbism, but this device does not seem to be a reliable safeguard.

Both lead and iron pipes suffer from deterioration of the metal in certain soils, and in particular if there be sulphides in the soil in which they are laid. Streets bottomed with slag are particularly destructive to the tenacious properties and to the crystalline structure of cast-iron. In Coatbridge the iron mains become quite altered in their character after about ten years. The iron becomes so friable that it can be cut with a penknife, like graphite. The molecular structure is no longer fibrous, and the pipe becomes very liable to burst. Lead pipes undergo a somewhat similar transformation, and the outside parts tend to break up and scale off, leaving a pock-marked surface.

Protection of Iron Pipes.—The protection of iron mains from internal corrosion is a most important matter from the economic point of view, and no less from the side of the palatability of the water. Unfiltered water from uplands is often found to corrode iron mains and scraping limits, but does not cure the evil. The means taken to exclude *Crenothrix* is described at p. 333. There can be little doubt that a preliminary filtration of the water before it is led into the mains is the surest remedy for corrosion of this nature. It not only saves the larger pipes, but it protects the whole distributing network.

The coating of iron pipes by Dr. A. Smith's patent process has been found to make the surface rust-proof so long as the covering film of pitch remains intact. The coating is applied immediately after the pressure tests have been made, and before any rust has formed on the surface. The coating composition is a mixture of gas oil and tar in the ratio of 1 to 2. The pipes are heated in this to a temperature of 420° F., the tar gradually evaporating till very little remains. On being

withdrawn, the hot pipes throw off any volatile solvents adhering, and a thin hard coat is left.

When finished, the coated pipes should not be placed near the dipping-pot in which the tar and oil are heated, for the fumes of tar driven off are likely to condense on the film, and give the water a tarry flavour when they are newly laid. In fact, it has been found best to recoat any pipes which have had their covering softened by the fumes driven by wind through the interiors.

Smith's coating is gradually eroded by a supply water carrying sand or other sediment. Scrapers break it up, and allow the water to act on the metal. The soil in which the track is dug may affect it, and allow rusting to set in; but in general it is a valuable means of conserving the metal and preventing loss of carrying power. The latter is equivalent to serious depreciation of capital. We read of a line of thirty miles of iron pipes laid down to deliver 2,000,000 gallons per day being so corroded in nine years that less than 1,500,000 gallons was carried. Such a loss of carrying power—roughly 3 per cent. per annum—would be ruinous to most water companies.

ACTION OF SERVICE WATER UPON LEAD PIPES.

The solution of lead in waters gathered from moorlands resulting in the symptoms of lead-poisoning among consumers has drawn special attention to the action of water upon this metal. For some time previous to the year 1894 the Local Government Board had been engaged in investigating the nature of this action, the causes which favour its operation, and the remedies that might be applied to prevent it.

It was ascertained definitely at that time that, whereas spring water is without solvent action on lead, peaty water —that is, water draining from peat—is acid, and such water always dissolves lead. Moist peat is invariably acid. Peat which has dried, rapidly develops acidity when again moistened. The acids which are characteristically present are humic and crenic, and they are by-products of the vitality of certain bacilli. The latter have more recently been isolated and studied by Dr. Houston.

Supplies drawn from moorlands rarely consist of peaty

water alone. There is generally an admixture of water which has had an opportunity of percolating through soil and the underlying strata, and of taking up some proportion of mineral matters. Water of this description added to that which has drained from peat exercises upon it important influences. In sufficient quantity, it may neutralize the acidity of the peaty constituents, and render the supply quite harmless. Dr. Houston found that during dry weather—markedly after some continuance of drought—moorland waters show no acidity and lose their lead-dissolving potency. On the other hand, a downfall of rain soaks through the beds of acid-laden peat, and descends to the watercourses in quantity, making the general supply acid and plumbo-solvent.

It follows from this that the greatest attention should be directed to the quality of a moorland supply during wet weather. We are familiar with the dark brown colour which many mountain streams assume in time of flood. That is the result of the rain washing out the acid liquids stagnating among peat. A reservoir which has received a large contribution of storm water may continue to hold acid water long after the inflowing streams have ceased to bring down peat washings. Unfortunately, in most cases the reservoir has been constructed for the purpose of conserving some part of the extra volume available in wet weather, so that the admixture of water derived from deeper sources may be of little avail. The first washings of the peat are always the most heavily charged with acids, and considerable advantage is obtained by letting these go by. It is also undesirable to permit loose fragments of peat to be washed into the reservoirs.

Experiments on Moorland Supplies.—The experiments carried out under Dr. Houston's direction with the Shipley water-supply during the two years following February, 1894, are of great interest. The results are detailed in the Supplement to the Thirty-first Annual Report of the Local Government Board (1901-02), pp. 127-135. The reservoir water was always acid, and the amount of lead dissolved in a given time by a measured quantity of it was found to be directly proportional to the degree of acidity. The solvent action was pronounced, for about 2 grains of lead could be taken up per gallon during three minutes' contact with lead shot

The quantity dissolved in this way varied from time to time, always keeping pace with the acidity, and ranging from 1 to 4 grains per gallon. Neither in this case nor in any of the other supplies examined could the solvent action of the water be connected with any other impurity than that already mentioned. At Mossley Reservoir the incoming water is treated with whiting ($1\frac{1}{2}$ grains per gallon), to neutralize acidity, and the effluent water is only faintly acid, and scarcely attacks lead. Prior to the adoption of this treatment, the reservoir contents showed an acidity equal to about one-third of that of Shipley, and the solution test applied as described above gave rather less than $\frac{1}{2}$ grain per gallon.

Of special significance were the tests made at the Bacup Waterworks. Simultaneous experiments were made with samples of the incoming and outgoing water. The latter was always acid and plumbo-solvent. The former was at times almost neutral, but after heavy rains its acidity excelled that of the reservoir water. The important point here is that impounded water may be continuously plumbo-solvent, even though the inflow is neutral for considerable periods throughout the year.

Dr. Houston's experiments established the fact that acid moorland water takes up lead very quickly. In general the samples were allowed to filter through lead shot. A pound of the shot being placed in a suitable vessel, the water was made to percolate upwards at such speed that about 1 cubic inch was delivered per minute. Variations of speed made little change in the amount dissolved, even when the water passed two or three times more slowly; and Shipley and Mossley water dissolved as much in forty seconds as they were able to do in three minutes. Hence it is clear that rapid transmission through lead pipes is no safeguard against plumbo-solvency.

Remedies for Plumbo-Solvency.—The remedy which naturally suggests itself is the neutralizing of the acidity. This ought to be so carried out that the expense may be low, and that no detriment may be otherwise caused to the supply water. Dr. Houston made a series of tests with a variety of substances. In the first place, he discovered that a highly plumbo-solvent water like that at Shipley could be deprived

of its objectionable characters by mixing with a relatively small proportion (10 to 15 per cent.) of a hard water. He caused the raw water to filter through different substances, as limestone, chalk, marble, coke, polarite, flint, river sand, asbestos. The substances akin to limestone proved satisfactory when the rate of percolation was slow, and about 5 feet per hour appeared to be a safe speed.

Good results also followed the use of river and sea sand, but their powers of neutralizing the acid water were not permanent. The other substances tested were less satisfactory. Coke was in general inferior to polarite.

The permanence of the good effects of filtering through limestone was then inquired into. It became evident that after two days the neutralization was less complete, and in a week's time the plumbo-solvency was not much below that of the raw water. In short, the lime had taken on a coating of slimy vegetable matter, which obstructed the natural dissolution of it in the water. To remedy this, the water was prefiltered through asbestos, and in consequence the corrective action of the limestone went on for six weeks in a satisfactory manner, with only one or two unimportant failures. The asbestos therefore retained the suspended impurities which clogged the limestone. The experience gained at different waterworks shows that a layer of granulated chalk placed under the top layer of sand in the filters is an efficient corrective to acidity for a considerable length of time. It is necessary to keep the surface of the limestone clean and fresh, so that it may the more readily pass into solution. Neutralization by alkaline solutions, as sodium carbonate, lime-water, limestone-water, was always an effectual remedy.

Influence of Mineral Acids.—Storage of acid peaty waters does not materially improve their condition with respect to plumbo-solvency. Certain minerals were suspected of conferring acidity on natural waters, and among these iron sulphide (FeS), bog-iron ore, shale, etc., were tested, but negative results were deduced. On the other hand, the bisulphides of iron, known as marcasite and iron pyrites, treated with pure water for a few days at a time, render it acid and able to dissolve lead. Placed in contact with peat, these minerals materially increase the acidity of the water which soaks

through. Water from coal workings is frequently acid, but the particular acids present are not so capable of dissolving lead as those from moorlands. In other words, peaty acids are more active solvents of lead than mineral acids, a weak solution of the former being able to carry as much of the

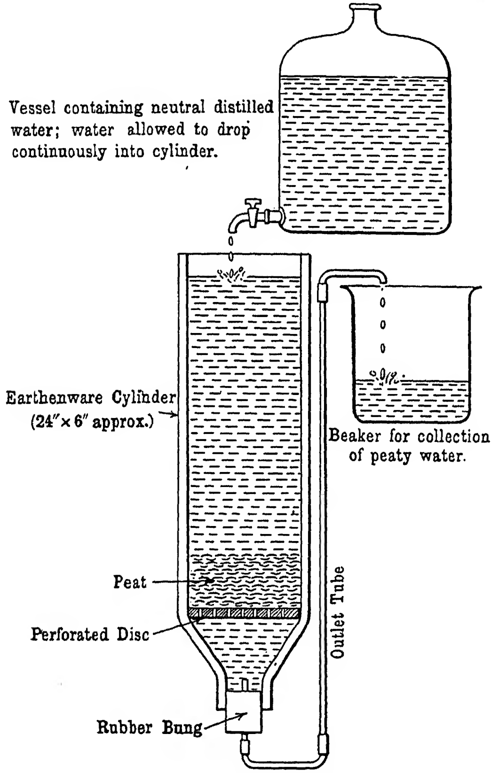


FIG. 93.—DR. HOUSTON'S APPARATUS FOR EXAMINING EFFECT OF PEAT.

(After Supplement to the Thirty-first Annual Report of the Local Government Board, Plate VI., by permission of the Controller of H.M. Stationery Office.)

metal as a far stronger solution of the latter. Water containing these mineral acids is less easily rendered innocuous by the addition of hard water.

Power of Peat to develop Acids.—The power of moist peat to confer plumbo-solvency upon distilled water, and consequently on rain water, is remarkable; for if a given weight of

peat be submerged in water, it is capable of rendering twenty times its own weight of the water decidedly plumbo-solvent. And if the exhausted peat be suffered to dry with exposure to the air, it recovers its acid-giving powers, and may in this way impregnate the water which percolates subsequently, over and over again. By suitably-devised experiments, Dr. Houston proved that, with alternate drying and submerging, peat might confer dangerous acidity on two hundred times its own weight of water.

To illustrate the action of water stagnating in pools and depressions among peat, the apparatus illustrated (Fig. 93) was set in operation. Natural conditions are here closely imitated, and the conclusion arrived at was that 1 pound of peat is able to acidify from one to four hundred times its own weight of rain water or distilled water. Even hard limestone water may be converted into a lead-dissolving fluid if the salts of lime present are not sufficient to make the mixed liquids neutral.

Origin of the Acidity of Peat.—As to the origin of acidity in moorland waters, Mr. Power has advanced a theory which receives support from Dr. Houston's investigations. It is that certain bacteria through their activity set free the acids in moist peat. Two microbes in particular were isolated and described, which can render a neutral and sterilized decoction of peat plumbo-solvent. To their activity may be ascribed the acidity of moorland cases in most instances. Occasionally, no doubt, the chemical changes which accompany the oxidation of pyrites give rise to acid waters in the gathering grounds. It has been noted, too, that rain water in the neighbourhood of the great manufacturing towns has appreciable acidity; but this circumstance can only play a quite unimportant rôle in determining the plumbo-solvency of moorland sources.

Erosion of Lead Pipes.—We defer consideration of the most suitable and practical means of counteracting acidity on a large scale until a second effect of natural waters upon lead has been dealt with—the action which goes under the name of "erosion." This may be shortly defined as the eating away of the surface of lead, particularly of the bright and clean metal. Coated lead, which by exposure to the air or by contact with hard waters has acquired a surface covering of

oxides or other compounds, is not subject to erosion. The property of corroding and eating away the exposed surface of lead seems to be due to oxygen dissolved in the water in contact. Hence most natural waters would erode were it not for the fact that they very often deposit on the lead an adherent coating, which puts a stop to further action. Both rain water and distilled water erode clean, scraped lead. Erosion, properly speaking, consists in the formation of a nearly or altogether insoluble compound, which is but loosely attached to the lead surface, and does not inhibit continued action of the same nature. It differs entirely from plumbo-solvency, and, beyond its destructive influence on the pipes, it has probably no consequences obnoxious to the consumer. At times erosion and plumbo-solvency go on hand in hand. The latter is by far the more dangerous, for, though it is true that the lead compound formed by erosion—oxyhydrate of lead, $Pb(OH)_2$—scales away and mixes with the current, it would not seem to have been shown that lead-poisoning is induced thereby.

Plumbo-Protective Substances.—We have said that the deposit formed on the surface by non-eroding waters affords a permanent shield against further erosive action by them. It has been shown in the Local Government Board's Report above quoted that lead which has received a coating after contact with a hard water is not easily eroded by waters which would readily attack the scraped metal. Those substances which serve to inhibit the erosion of lead are called "plumbo-protective," and they are chiefly those which impart hardness to a water. Thus, chalk, sulphates of lime and magnesia, common salt, and carbonate of ammonia, belong to this class. The bicarbonates of soda and lime and the carbonate of soda are excellent preventatives.

Reserve of Protective Power.—Of waters which do not erode lead, there are some which contain but very small quantities of plumbo-protective substances. If a sample of this kind be taken and placed in a beaker with bright lead, a coating is formed, and no further action ensues. If now the lead be scraped clean and replaced, a real erosion may take place; and if so, it will be progressive. In other cases the lead may have to be scraped and replaced several times before the plumbo-protective substance in the water is exhausted.

Waters which possess little reserve of plumbo-protective substances, and are consequently on the borderland of erosion, merit the careful attention of those who have to deal with them. Slight changes in the relative proportions of the different feeders may very well bring their erosive powers into play. In providing remedies for erosion, it is well to endow the water with some reserve of plumbo-protective ability. That is not difficult, for it is only necessary to get chalk, or limestone, or any other form of the carbonate of lime, into solution. Equally good and more readily dissolved is carbonate of soda, which can be recommended in cases of emergency. Its cost is greater than that of the carbonate of lime, but, owing to its great solubility, it can be applied much more conveniently, and without any special apparatus beyond a perforated tube over the intake.

Acid moorland waters usually erode, while neutral samples of the same do not. But it was shown by experiments that these neutral moorland streams are not far off from the possession of erosive power. As Dr. Houston says, they are potentially dangerous. The addition of a little carbonate of soda removes all risks. The amount of carbonate mixed with the acid water must be at least sufficient to neutralize it. It is advisable to have some slight excess. Less than the quantity which will be taken up by the acids is useless. One of the best ways of fortifying the supply against erosion is to apply a treatment in two steps. First, the water is brought into contact with chalk—by filtration, for example—so that it is deprived of erosive potency. It then receives a very small dose of sodium carbonate (1 in 200 or 300). Repeated renewals of bright lead do not then lead to any action.

Lime is far inferior to these carbonates as a preventative, because the film of oxide forms on the surface with reluctance.

Filtration through sand does not give very reassuring results, for, though there is often a partial neutralization of acid water, and corresponding arrest of erosion, the good effects disappear so soon as the soluble matters among the granules have been dissolved out. Sand which has been washed in a weak mineral acid and then rinsed in clean water does not prevent erosion. Alloys of lead and tin (4 per cent. tin) inhibit to some extent erosive action, but they are not to be relied upon as an adequate preventative. Likewise, lead

coated inside with tin is able to resist attack—for a time, at least—but it is far from being a sure safeguard.

Protective Treatment on a Large Scale.—The treatment of moorland waters on what may be called a commercial scale presents difficulties which only experience is able to bring to light. Each supply must be considered apart, so that one may arrive at a procedure which will be at once effective and as economical as possible. The working should be as far as possible automatic, but if the conditions vary much with the recurrence of drought and rainfall, as most frequently occurs, it will be advisable to make due preparations for adjusting the treatment to the changes that are anticipated. Intelligent supervision must therefore be provided for. Though plumbo-solvency and erosion are quite distinct, and arise from different causes, it is fortunate that the treatment which rectifies the one will also correct the other. It may, however, be necessary to carry the process which serves to hinder solution a little farther, in order to strike at erosion with certainty. It was demonstrated by Dr. Houston's work that a moorland water which had been neutralized so as to make its solvent action negligible might still vigorously erode. After being filtered through limestone, such a water might be safe as regards solvency, and unsafe with respect to erosion; or, if not actually erosive, it might be near the possession of erosive ability. These considerations may help to throw some light on the difficulties of arriving at a scientific mode of procedure.

Treatment applied at Various Places to remedy Plumbo-Solvency and Erosion; Water-Hardening.—As illustrating the method of dealing with a typical moorland water, the case of Wakefield may be referred to. This supply experiences all the vicissitudes of waters drawn from similar sources. The catchment area is on the whole rich in peat, and while during fair weather there is a good volume of spring water, the amount of surface acid water is great during periods of rainfall. Tested in October, 1894, the various intakes were each and all neutral, because the preceding month had contributed less than 1 inch of rainfall. Nevertheless, the water in the reservoir which had not been treated was distinctly acid.

At that time the practice was to mix a strong solution of soda with the water as it enters a second reservoir, in the proportion

of 1 gallon of the alkaline liquid to 2,000 of the raw water. Neutralization was thus completed. The soda was brought into a series of barrels connected by pipes, and through these a current of water permeated. This treatment, which resulted in the addition of about 3½ grains of soda per gallon to the raw water, was an expensive one, averaging 20s. per million gallons. It has been superseded by the following procedure: Chalk of the best quality is finely ground and placed in a hopper, from which it is gradually washed by regulated jets of water that play upon it from below upwards, and so much of the milky fluid is led to the inflow as will add 1 grain of chalk per gallon. Were a larger dose introduced, the filters would clog. Further, it was found that the sand-filters were apt to reduce the alkalinity of the water which passed through, especially when the sand was fresh. To add an alkaline solution to the water before filtration would therefore be uneconomical. Hence the neutralization is completed on the filtered water. Two grains of lime per gallon are added. This is carried from hoppers in the same way as is the case with the chalk. The treatment is an effective one, for the service water is no longer plumbo-solvent, or, at least, the amount of lead that has been found upon occasion in solution may be classed as a trace.

At Burnley the acid water from one source was treated with milk of lime—120 pounds per 1,000,000 gallons. This was introduced to the raw water by means of a chain with buckets driven from a water-motor. The plumbo-solvency was not wholly corrected, but the application of a larger amount of lime would have clogged the filters.

With the mechanical filters tested at Burnley, lime-water was first tried, but that proved unsatisfactory from the limited solubility of lime. Hence it was replaced by carbonate of soda, and this chemical served as neutralizer, while so much sulphate of alumina was also added to precipitate the peaty matters.

It was necessary to put in as much carbonate of soda as would react with the alumina, in addition to the amount required to neutralize the peaty acids. The solutions of the two chemicals were prepared in separate tanks, and conveyed to the intake by pumps driven from a turbine in the main flow. The dose of soda was regulated to 80 pounds per 1,000,000 gallons.

It was noticed before the carbonate of soda treatment was begun that the tap water in the town was occasionally plumbo-solvent when the reservoir water was neutral, or nearly so. Upon investigation of the lead pipes, there was discovered a peaty slime adhering to the inner walls, which could be scraped off without difficulty. This slime was placed in water along with lead pipe, and it exhibited distinct plumbo-solvent properties. Hence the need of abstracting peaty substances from the service water ; otherwise such slimes may accumulate in the pipes and bring about lead-poisoning.

At Sheffield, where the high-level supply is distinctly peaty in character, the acid is neutralized by the addition of whiting. There is an ingenious arrangement whereby 2 grains of the chemical are added to each gallon. This is rather more than the water is able to dissolve, and the treated water is then conveyed along a channel a distance of some miles. It thus loses its milkiness, and arrives at a lower reservoir clear and neutral.

At Keighley Corporation Waterworks an entirely different method was put in operation. The acid water is filtered through a top layer of coke, then sand and gravel, and in sequence broken limestone and polarite. The upper layers were of great use in protecting the limestone, which is responsible for the neutralization, from attracting a coat of slimy vegetable matter. This device, on the whole, has yielded satisfactory results.

Less to be recommended is the practice which was tried at Morley, where the sand-beds were covered with a layer of pulverized limestone. So soon as this became obscured by a growth of algæ and other vegetable forms, the limestone ceased to dissolve in the water, and the original acidity remained. An attempt was made to remedy this by discharging lime into the reservoir from rafts, and later some soda was also applied to the service water. From the experience gained here and elsewhere, it would seem that the limestone should not form the top stratum of a filter-bed.

Dr. Houston is inclined to recommend filtration through intercalated layers of sand and chalk, the sand being, of course, on the surface. He suggests the addition of a small dose of carbonate of soda to the filtered water, so as to provide it with some reserve of plumbo-protective ability. Erosion would thus be made a " remote " contingency.

Moorland waters present many peculiarities which pure theory could not have anticipated. Waters which were shown by analysis to be hard were not seldom very acid. Thus, the plumbo-solvency does not run parallel with the softness. It also is true that peaty waters will not take up any large proportion of carbonate of lime ; yet, when the acidity has once been neutralized, the water does not in the ordinary course of distribution regain any power of acting on lead.

Much may be done, by careful attention to the gathering ground, to correct the action of the service water on lead. Each gathering ground which partakes of the nature of moorland requires to be examined and studied with regard to its own characteristics. Treatment may thus be rendered unnecessary in many cases. The chief aim should be to exclude acid-bearing waters as far as is practicable, and to bring in as great a volume of spring water as it is possible to tap.

In particular, the first washings of the peat may be thrown aside by means of "leap" weirs, and the débris of marshy grounds is retained in "wreck" lodges and stone filters. Great harm results from allowing water to lie constantly in contact with peat in hollows and other natural depressions. By-channels should be dug to drain all such, for they are simply extracting sumps which mature a rich brew of acids, to be carried away to the intake streams at every downpour of rain. A moorland supply may be rendered innocuous by admixture with water derived from deeper sources. Thus the water of Swineshaw Reservoir, which is acid, on being mixed with equal parts of Wicken Springs (Ashton-under-Lyne, Stalybridge, and Dukinfield Waterworks), becomes neutral and non-solvent of lead.

Erosion and plumbo-solvency may both result from the same water, but the treatment which corrects the latter will most likely obviate the former. If there be a fair proportion of spring water, erosion is less likely to occur. The coating which forms on lead by exposure to the air or by immersion in hard water is of little use in preventing plumbo-solvency. If, however, a natural water is able to deposit this coating, in virtue of the salts which it holds in solution, no further erosive action need be anticipated, and the lead pipe will be unharmed, unless, of course, the water be plumbo-solvent.

For full information regarding all the matters discussed in

this chapter, one must refer to Dr. Houston's classic reports, which not only show how these influences of water on lead were traced to their prime causes, but also afford details of the conditions prevailing at many waterworks affected, and include valuable suggestions as to the best way of remedying defects in the service supply.

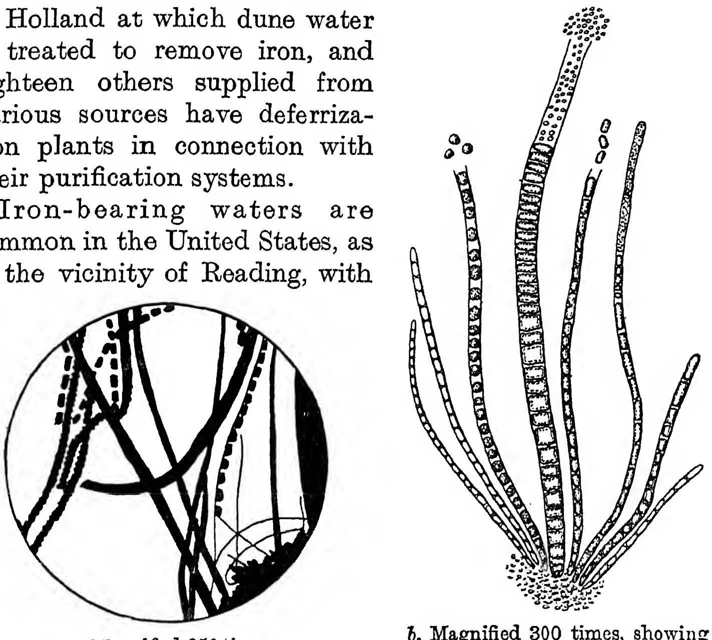
LOSS OF CARRYING POWER IN IRON MAINS.

The action of water upon iron has been the subject of numerous researches on the part of Moody, Friend, Crum Brown, Walker, Goulding, and others. Recently Professor Tilden (*Jour. Chem. Soc.*, 1908), in revising the whole ground, concludes that the purest water is able to cause slow filming of the exposed surface with hydroxide of iron—$Fe(OH)_2$. Dissolved oxygen greatly hastens the attack, with the formation of rust, and carbonic acid is an active ally. There is probably an electrolytic effect in consequence of impurities in the iron, as embedded graphite, scale and compounds of phosphorus, silicon, carbon, and sulphur. However that may be, there is formed on submerged iron in ordinary waters a coating of oxides and carbonates which is to some extent friable, and liable to be detached in quantity by scour. The iron also passes into solution, for the ferrous carbonates are taken up by natural waters with more or less freedom, according to the salts and gases that may be present. The river supply at Paris can take up $\frac{1}{5}$ grain per gallon from bright scrap ionr in a very short time.

The *Revue d'Hygiène*, vol. xxx., 1908, contains an exhaustive article by M. H. Schwers upon the occurrence of iron in underground waters in Germany and the Netherlands, and the methods of deferrization practised. Schwers is clearly of opinion that the dissolved iron in such cases is either in the colloidal state as hydroxide, or is in chemical union with carbonic acid or with organic bodies, as ulmic acid. The solution of iron from rocks mineralized with that element is activated by carbonic acid, and this gas also keeps the iron in solution. Any treatment applied for the removal of iron should be based on full cognizance of the condition under which the water holds it dissolved. With a few exceptions (as Cuxhaven, Greifswald, Lübeck, Moers), the underground

sources of North Germany are freely charged with iron. Some springs near Bremen have 6 grains of iron per gallon; those at Posen, about 1 grain; at the Berlin-Tegel supply and at Kiel, 0·12 grain, with somewhat less at Hanover. Many of the underground supplies in the Netherlands contain iron, and in particular the dune water holds 0·06 grain per gallon; Sloten water, 2 grains; Tilburg water, 0·2 grain per gallon. There are at least twelve stations in Holland at which dune water is treated to remove iron, and eighteen others supplied from various sources have deferrization plants in connection with their purification systems.

Iron-bearing waters are common in the United States, as in the vicinity of Reading, with



a, Magnified 250 times.

b, Magnified 300 times, showing the mode of growth.

FIG. 94.—CRENOTHRIX.

from 0·01 grain to 1·3 grains per gallon; Shelby, with 0·6 grain, etc. Several supplies of consequence in Britain contain iron in solution. There are few such in France or Belgium.

Yet the twofold action of rusting and dissolving which natural waters bring about is much less detrimental to the carrying power of iron mains than the influence of certain lowly organisms which flourish under favourable conditions in the dark interior of the pipes. The microscopic Crenothrix (Fig. 94) readily makes a breeding-ground of the water mains, if only there be a sufficient amount of dissolved iron in the

water. Other species which can flourish in water holding iron in solution are Cladothrix,* Gallionella, Spirophyllum, and Leptothrix. The vitality of Crenothrix is in some way bound up with the secretion or separation of iron from the water into the tissue of its cell walls. Located there, the iron becomes oxidized, and as the Crenothrix multiplies filaments discoloured with ferruginous matter become visible. Tangles of these growths attach themselves to the interior of the pipes, and in time they indurate and become part of the walls. The bore of the pipe gradually contracts, and the carrying capacity may diminish by 1 per cent. yearly. Fluctuations in the current and regurgitations detach loose granular fragments, which discolour the outflow and occasion odours that are far from agreeable. Crenothrix never infests waters that are free from dissolved iron. Its demands on that element are, however, easily satisfied, and therefore, in adopting the only radical cure for this undesirable organism, it is needful that the treatment should be thorough. The dissolved iron must be eliminated.

Dr. D. Ellis has shown that it is Leptothrix and not Crenothrix which mostly causes the choking of pipes in Britain. He attributes the evil effects of iron-bacteria to the fact that their filaments are gelatinous, and persist long after the death of the organisms. Ferric hydroxide accumulates on these. They grow rapidly wherever the full conditions of their existence are realised. The reservoirs at Cheltenham in 1896 were found to be teeming with Crenothrix, but the organism has not again caused trouble there.

The Removal of Iron from Underground Sources.—According to Schwers, it is advisable to make deferrization as complete as possible. He thinks that 0·1 part per million should be regarded as a maximum for the filtrate. Undesirable precipitations of oxide from the mains appeared at Leipzig, Stade, Posen, Munich-Gladbach, and elsewhere, where the removal of iron had been less thorough. It is known that Crenothrix flourishes in a solution of 0·3 part per million, and less may occasionally suffice for its activity.

It is a matter of experience that waters with much iron

* These bacteria require some organic matter for their development. Dr. D. Ellis has shown that Cladothrix thrives in iron-free water. See also Kolkwitz (Biblio., p. 359).

dissolved are often easier to treat than those with small percentages. Kiel water, with 1·3 parts per million, is relieved of 95 per cent. by the removal process ; while at Hanover only about one-half of the iron content (0·25 part per million) is similarly brought down. The precipitation of the iron depends to a greater or less extent upon the other salts which are in solution along with it, as those of calcium, magnesium, manganese, aluminium, with the combining acids, sulphuric, carbonic, phosphoric, ulmic, silicic. It is to the different proportions of these other bodies in solution in the natural water that we must ascribe the greater or less difficulty of getting rid of the iron.

Principles guiding the Removal of Iron from Water.—There are three physico-chemical processes applicable in deferrization, according to the condition in which the dissolved iron is held. In very many cases aeration, with subsequent filtration, suffices to reject almost every trace of iron, because the oxidation of ferrous salts (and of free iron ions) is not hindered by any other substance that may happen to be present in solution

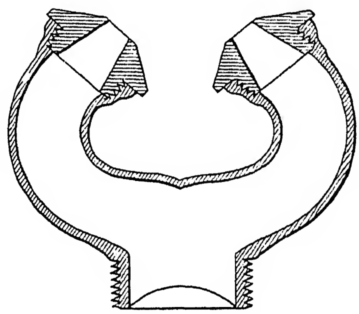


FIG. 95.—SPRAYING NOZZLE.

At Amsterdam the dune water is sprayed over the prefilter by means of nozzles of the form shown in Fig. 95.

When, however, the iron occurs in the colloidal state, as may be the case when it is united to organic substances, it is better to treat the water with an agglutinating chemical, as sulphate of alumina, ferric chloride, or such. Lastly, the iron may be held up by carbonic acid gas. In a sense, this is not a distinct case or condition, since it is likely that carbonic acid always plays a part in keeping iron in solution in natural sources. Aeration converts ferrous carbonate into ferric, and this change is followed by precipitation. Neutralization by milk of lime renders the carbonic acid impotent, and the iron then submits to the aeration procedure.

The experiences at various stations in Germany have not

always been satisfactory. At Hamburg* the addition of chalk and sulphate of alumina led to no useful purpose, while the increase of hardness was an objection. A similar process has been in use at Crefeld to purify a ferruginous water for industrial requirements. Piefke, who has given attention to this subject, made trials with chalk and ferro-chloride, but without arriving at any definite conclusion as to the applicability of the method with different kinds of water. He has also designed an aerating tower, in which the crude water passes over coke, and the contained iron, being thus rapidly brought into the ferric state, is filtered off. The coke-tower has rendered excellent service in Charlottenburg and at Salbach. The city of Berlin introduced Piefke's process a few years ago to deal with the supplies from Tegel and Müggel. There are in Germany nearly a hundred installations at which deferrization is an essential part of the purification. The procedure generally adopted is to aerate and filter.

The methods of aeration vary. In Leipzig the raw water is made to dissolve air at a pressure of four to five atmospheres in a special chamber, after which it is further exposed to the air in a conduit twenty miles long. Cascading, spraying, distribution, and circulation, are among other plans of arriving at the oxidation desired.

Intense aeration and subsequent filtration at Amsterdam reduces the dissolved iron from 0·8 part per million to nil. At Freeport, Illinois, lime is added to the raw water, which is then carried to a Jewell plant. Very little iron remains—never sufficient to permit of the reappearance of Crenothrix. Before this practice was adopted the service water was at times almost unusable. At different places in England filtration through oxidium or polarite yields an iron-free filtrate (p. 189).

Mr. R. Spurr Weston has discussed the purification of ground waters containing iron and manganese, with special reference to experiences in the State of Massachusetts (Proc. Amer. Soc. of Civil Engineers, vol. xxxiv., pp. 1324-1393, 1908). He also points out the importance of studying the factors which play a collateral part in the solution of iron, as the presence of electrolytes, concentration of positive or negative colloids, and organic matters. He refers to the good results obtained by H. W. Clark (1896) by passing the raw water through rotating

* For water from underground sources.

cylinders filled with iron filings or coke impregnated with iron.

Considerable difficulty has been encountered in treating the supply of Reading, Mass., which contains some manganese (up to 0·6 part per million), in addition to varying amounts of iron. The water is partly moorland. Aeration with sedimentation for weeks produced but slight effect. Treatment with filings and with finely divided iron was unsatisfactory. For a period of ten years the water company proceeded with the application of chalk and sulphate of alumina. The chalk was added in the proportion of 1 pound per 1,000 gallons. Mr. Weston replaced the chalk by clay—a substance which in colloidal suspension bears a negative charge of electricity, and is thus oppositely electrified to colloidal iron. Neutralization follows. The subsequent addition of sulphate of alumina clears the water, clay and iron oxide both falling out. The action of the clay may be understood when one recalls the fact that the precipitation of clay itself by sulphate of alumina depends on the circumstance that the latter yields a colloidal hydrate which has a positive charge. Just as the clay acts on the iron, so does hydrate of alumina interact with clay and produce a neutral agglomeration of particles which readily separate and sink. Since the improved system has been in operation, sedimentation basins have been constructed, and the treated water is rough-filtered before being led to the finer sand.

Mention has been made of scour in iron mains due to flux and reflux of the water stirring up the gatherings of loose oxide in the pipes, so that the tap water shows brown, and a brick-red sediment falls out on standing. If this be at all a common experience, it is plain that the mains are in a dirty condition, and that rust is carrying on a vigorous attack. A temporary remedy is found in artificial scouring, which consists in opening a main at its lowest point, and allowing free outlet to the water so long as it is seen to be discoloured. Good effects follow the use of a scouring-brush, or "hedgehog," which is let into the main at its highest point, and this, drifting on with the current, rids the pipe of loosely adherent matters The brush can also be hauled through successive lengths of the mains by attaching a drag-line. This procedure is necessary if there are gross obstructions, such as intrusions of lead at the joints.

CHAPTER XIII

THE PROBLEMS OF DISTRIBUTION—*Continued*

Water-Hammer.

Among the agencies which give rise to defects in a distribution system, there is one which is apt to be disregarded by the water engineer, probably because he is not aware of the magnitude of the forces which it calls into being. Water-hammer subjects the joints, pipes, and fittings, to very great strains, suddenly applied pressures of two and three hundred pounds per square inch not being out of the common.

The immediate cause of water-hammer is the quick closing of outflow taps. The current is thereby arrested, and the inertia of the column of water moving along the pipe sets up a compression at the tap end. This compression travels backwards along the length of the pipe with speed, thrusting at every portion of it in succession until the compression wave reaches the intake, which is generally the street main. From there the wave returns with a somewhat diminished force, and is again reflected from the tap. This oscillation of the compression is an established fact, which accounts for the continuance of hammer long after the shutting down of the tap which was the cause of it.

To calculate the maximum pressure which water-hammer exerts on the pipe, it is only necessary to multiply by 60 the rate of flow in the pipe in feet per second immediately before the cut-off. The product gives the pressure in pounds per square inch. Therefore, to shut off quickly a current issuing at 4 feet per second brings into play a force of 240 pounds per square inch on every part of the supply-pipe. With large mains the thrust is somewhat less than this—probably about three-quarters.

To Professor Joukovsky, of Moscow University, is due the credit of having investigated the whole question of water-hammer, and he has supplied a complete solution of all the problems which arise in connection with it. It was, of course, well known that hammer could be avoided by shutting down the tap slowly; but Joukovsky has given us a means of knowing the precise length of time that should be occupied in shutting off, if the worst effects of hammer are to be avoided. It should not be less than the time occupied by the compression wave in travelling from the tap to the water-main and back. Fortunately, this is usually a fraction of a second only, for the compression wave is propagated with the high velocity of rather more than 4,000 feet per second. Hence, if the service pipe is 200 feet long, the trip of the compression wave to and fro occupies one-tenth of a second, and if the cut-off lasts longer than this the pipe escapes the maximum strain. When the duration of the cut-off is still further prolonged, the intensity of the back pressure decreases, and when it becomes three or four times the period of the double trip of the wave, the effect is of little consequence.

We see, therefore, that there is an easy means of avoiding hammer in service pipes, and it is recommended that all taps should be of the screw-down type, so as to prevent householders shutting off the water almost instantaneously. Ground cocks of the gas-tap pattern are so constructed that they give the householder a too handy instrument for checking the outflow suddenly. The common ball-cock valve in cisterns is a frequent cause of hammer, because at the last moment the flow is cut off abruptly. Self-closing fittings are in general apt to check the outflow suddenly and cause water-hammer.

There are other devices for insuring the safety of the service pipes. The best arrangement is to introduce a safety-valve on the house pipe, the valve being held down by a spring of suitable strength, adjustable to circumstances. The type of safety-valve used in Moscow is shown in the accompanying figure (Fig. 96). There are over 1,500 of these at work in that city, and since their introduction there has been no instance of damage to the pipes so provided, or to the joints in connection.

When a tap is closed suddenly, it is observed that the valve immediately rises, and allows a small quantity of water to

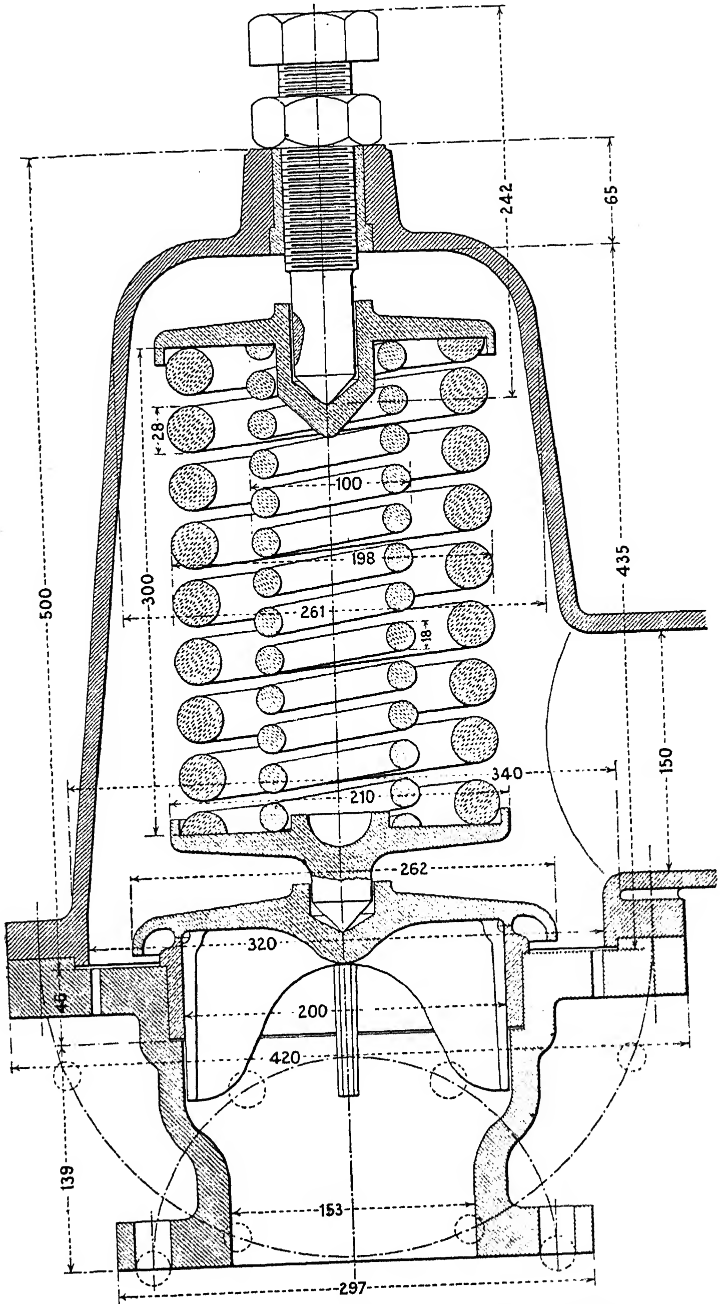


FIG. 96.—SAFETY-VALVE TO PREVENT WATER-HAMMER.
Scale $\frac{1}{12}$. The dimensions are given in millimetres.

escape, and this action is repeated once and again as often as the compression wave passes. The intensity of the pressure diminishes, and dies away quickly. At the first impulse the water is ejected with considerable force, and sprays out like a fountain. Succeeding outflows are less and less impetuous. The total loss of water is very small.

It has been suggested to replace the safety-valves by air-chambers, and these, if sufficiently large, relieve the excess pressure. It is, however, difficult to retain a supply of air over the water, as it is gradually dissolved, and the influence of the chamber becomes enfeebled. Joukovsky has shown that a pipe from which a branch is taken is more liable on that account to suffer from water-hammer, for the compression wave enters the branch, travels to the dead end, and is reflected back to the origin. It then advances into the pipe from which it branches, and reinforces the compression there, so that the resulting pressure may be twice as great at points. A branching system of water-pipes in a house is therefore specially in need of protection from hammer.

The larger water-mains in Moscow are also provided with safety-valves, to render them immune from hammer should any sudden check of the flow be occasioned—as, for example, by closing of fire-hydrants. Sixteen safety-valves have been placed on the twenty-five miles' stretch of pipe from the works to the city. The joints have escaped injury for many years.

It may be added that Professor Joukovsky noticed that the diagram of the propagation of a compression wave in a pipe, which can be recorded by special instruments, is altered by the occurrence of a leak in the pipe. He was subsequently enabled to show that this fact might be used to locate the leak within a few feet. Similarly, he was able to detect an air-pocket, and thus a very convenient mode of ascertaining the actual condition of an underground pipe was discovered as a result of the research on water-hammer.

ELECTROLYSIS IN WATER-PIPES.

Water which has no action on lead under ordinary circumstances may dissolve it freely if a current of electricity is passed along a lead service pipe. A case in point was reported from Twyford, Hants, lead-poisoning having been caused by

water which showed no acidity whatever. But electric connections to the house lamps were placed near to the lead pipe, and a leakage of current had been in progress. In order to ascertain whether the solvent power of the water was traceable to that circumstance, a current of electricity of the same voltage as the house supply was sent through a length of lead pipe filled with the service water. After some hours the water was found to have dissolved about $\frac{1}{10}$ grain of lead per gallon.

It is evident that electric wires for lighting and power should be kept apart from the water connections. They should not be "earthed" on the lead pipes. Even currents of low voltage (0·2 to 0·3 volt) seem to exercise some influence on the properties of the water. There is probably no risk from the current of a few cells, such as are used for house bells.* Drinking water contains so little mineral matter in solution that as an electrolyte it offers much resistance to the passage of electricity. Weak currents of electricity led to a water pipe would probably travel almost entirely along the metal. But with a current of high tension enough electricity is diverted through the water contained in the pipe to give rise to dissociation of the dissolved bodies, solution of the lead, and other phenomena of electrolysis. Carbonate of lead was found in the pipes at Twyford, thus indicating a combination between the metal and the carbonic acid held in solution in the water or dissociated from another base. If a positive current is brought to the pipe, we may regard the lead as the anode, which, as is well known, seeks to pass into solution in the electrolyte.

It is the opinion of most water engineers that iron pipes suffer from the effects of electric currents, and this is at least probable, seeing that iron is much more readily dissolved than lead. Certain changes on the outside of iron mains which receive high-tension currents would seem to indicate that electrolysis goes on in the moist earth surrounding the pipe. In this way the iron is slowly dissolved, and subsequently oxidized.

Thus, the introduction of electric traction to the streets of so many cities has brought with it a real danger to the underground conduits of water and gas. It is not merely the leakage of electricity, but the return current from overhead wires, which is passed on to the rails, does not confine its path to the rails

* See, however, *Water*, vol. viii., p. 236.

alone, but some fraction of it makes use of the pipes underneath as a conductor. As a result of investigations, a Committee appointed by the British Parliament framed four clauses which were to be inserted in all Bills and Provisional Orders seeking authority to use currents of high power. It is specified that the undertakers must provide insulated return conductors or uninsulated metallic returns of low resistance. Safeguards against damage to the property of gas and water companies are further insisted upon.

According to the evidence of Sir W. Preece, given before the Committee mentioned, "an electrical pressure (potential difference) between water and gas pipes leads to serious consequences. The outcome of that would be that in course of time the pipes which were connected with the positive side of the current would be decomposed, owing to the moist ground acting as an electrolyte." The technical adviser of the Board of Trade on electrical matters showed a piece of lead pipe which had undergone rapid deterioration, and he had no hesitation in stating "that the greater part of the corrosion was due to electric action." By experimenting he had also found that a current of 1 ampère would eat away 1 pound of iron in twenty-seven days, and 1 pound of lead in five days.

The Board of Trade have made stringent regulations with regard to the daily tests of insulation, to the prompt repair of leakages, to the proportion of the return current that may be permitted to stray from the uninsulated conductor to adjacent pipes, and with reference to several other matters in which the interests of water and gas companies might be affected by an installation of electric lighting or traction.

Electrical action has to do with the "rusting" of brass and iron fittings in cisterns, and at unions in service pipes. Here the contact of two metals, as lead and iron, under water forms a weak galvanic cell, in which lead forms the positive, and iron the negative, pole or electrode. The latter metal is gradually dissolved and corroded. With zinc and iron, or brass, the zinc suffers most, and in certain kinds of water it soon exhibits pitting and loss of thickness in the neighbourhood of the line of contact with the other metal. Soldered joints corrode under water owing to galvanic action, and a brass rod carrying the copper ball of a self-acting tap is attacked at the junction of the metals.

In the case of house fittings it is hardly possible to avoid unions of different metals. With lead cisterns there is no difficulty in making the connections with lead pipe. But if fittings of another metal must be put in, galvanic action may be prevented by interposing insulating washers of rubber or hard wood to prevent direct contact of the metals on the outside as well as on the inside of the cistern wall. Red lead painting is also more or less effective.

PUBLIC HEALTH AND WATER-SUPPLY.

The physical welfare of a community is closely related to the quality of the water which is used for household purposes. Water enters into the composition of foods, and is a necessary part of most dishes. It forms the largest percentage of common beverages, soups, and other soft preparations. It is the every-day drink of the young, of the worker, and of all who by choice or necessity employ it to allay thirst. Dr. Parkes, in his "Practical Hygiene," mentions that soldiers require nearly 1 gallon of water per day either in food or as a beverage, and in general adults use 2 to 4 pints as drink in some form or other, and obtain about half that amount from cooked foods.

Influence of Inorganic Salts on Health.—With regard to the inorganic substances conveyed by water to the human system, it is well known that small quantities of those which commonly occur are in no way harmful. Only when the hardness reaches a relatively high figure—say 20 to 30 parts of the carbonates and sulphates of lime and magnesia conjointly—does it appear that any decided effect on the health of individuals is noticeable. Very hard waters are said to cause constipation and such-like derangements of the digestive organs, and Dr. Parkes considered that half that amount of any one of these salts might by itself cause indigestion, more especially among people not accustomed to drink hard water. On the other hand, waters devoid of lime salts have been accused of causing rickets and weakness of the bony framework among the growing members of the community. This is denied by the authorities in Glasgow, where the water is soft, but in other places the introduction of spring water has been credited with an appreciable improvement of the physique of the children (p. 239).

The presence of common salt and sulphate of magnesia, which may figure pretty highly in well waters near the seaboard, is not considered to be objectionable, though the latter is aperient in its action, and the former adds to the work of the excretory organs. Iron, when present in sufficient quantity to give a chalybeate taste, has been known to cause dyspepsia, headache, or general derangement (Thresh, "Ex. of Waters and Water-Supplies," p. 84). Occasionally the salts of zinc, copper, lead, and barium, have been noted as occurring in service waters, and all these are injurious to health. Zinc carbonate may find its way into the water from galvanized pipes and from cisterns, and it is doubtful if these articles should be used in the distribution of the supply, unless it has been ascertained that the water has no effect on them.

Lead-Poisoning.—Lead-poisoning, with one or other of its attendant symptoms, anæmia, colic, debility, and lead paralysis, has been of frequent occurrence among communities supplied with acid moorland waters. Such minute contents as $\frac{1}{40}$ grain per gallon produce the characteristic symptoms with some people, while larger proportions, up to $\frac{1}{10}$ grain per gallon, do not seem to affect others. This was the conclusion to which Dr. Angus Smith was led by his experience. As lead persists in the system, it seems advisable to eliminate it altogether from service water, and, thanks to Dr. Houston's research work in this department of water purification, the best methods of treatment are available to all (Supplements to Thirtieth and Thirty-first Reports of Local Government Board, London). Wherever the supply includes gatherings from moorlands, the tap water should be carefully analyzed from time to time. There is no excuse for allowing this deleterious ingredient to reach the consumer, and water undertakers might well be held responsible for the evil results.

Flood Epidemics.—Dr. Parkes has brought forward much evidence to show that serious derangements of the stomach and bowels are caused by water carrying much matter in suspension ("Practical Hygiene," p. 38). The unfiltered Neva water causes diarrhœa among strangers, and like effects have been noticed at army stations in various parts of the world. It is probable that the putrescible matter and germs in unfiltered

water have more to do with malignant diseases of the digestive tract than silt, or grit in suspension. As to dysentery, there is no doubt that one sufficient and oft-recorded cause is impure water. The reports of the Army Medical Councils at home and abroad point to numerous outbreaks of that malady as the direct consequence of the use of foul water. Not less convincing is the history of municipal hygiene, it being a common experience that a recrudescence of dysentery cases follows the pollution of the sources of supply by the inflow of impure water. Wholesome well water has often been polluted by floods, with disastrous consequences. These "flood epidemics," formerly regarded as the inevitable aftermath of a period of flooding, have now been checked by the precautions taken at the pumping-stations against the intrusion of undesirable water.

The epidemic of diarrhœa at Chelmsford in July and August, 1903, after some days of heavy rainfall, is a case in point. There were over a thousand serious cases during the month that the onset lasted, and an inspection of the waterworks by the Medical Officer of Health showed that one of the reservoirs had received the washings of a garden with top dressings of road-scrapings, and possibly other matters. The surface overflow had carried some of this into the reservoir, as was evident when the water was drawn off. Immediately after the suspected tributary was cut off the advance of the epidemic was arrested. Of the population using the contaminated water, no less than 21·5 per cent. suffered from the disease.

Dr. Thresh examined samples of the infected water at the reservoir, and found abundance of *B. coli* and other bacteria characteristic of field manures. After the supply from this source was discontinued, the main body of the town water was tested by more than one analyst, and found to be unexceptionable.

It may be added that a portion of the inhabitants of Chelmsford did not take in the borough water, but were supplied from other quarters. The epidemic hardly touched this section, and this fact at once led the Medical Officer to the discovery of the origin of the disease.

Among other diseases which are supposed to be disseminated by water, there are two which have been the subject of particular investigation.

Impure Water and Cholera.—The unfortunate outbreak of cholera at Hamburg was clearly shown to have been brought into the homes of the citizens by untreated Elbe water. More recently cholera spread over the Valley of the Volga for three years in succession, towns on its banks being the chief sufferers (p. 35). Indian medical authorities have again and again seen good reason to connect the spread of this disease with impure water-supplies, and at the time of the visitation of cholera to Scotland in 1866, Dr. Stevenson Macadam referred to the striking coincidence between the abatement of the pest and the acquisition of purer service water (Transactions of Royal Scottish Society of Arts, vol. vii.). In the same year the cholera cases in Berlin were very unequally distributed between the houses supplied with good and bad water. In that part of the city which received the better supply, the number of victims was little more than half of those in the other districts. Copenhagen had suffered severely from cholera in the earlier part of last century, but after the introduction of a wholesome water-supply in 1859 it practically escaped the epidemic of 1866. The contrast between St. Petersburg, which was using a deal of unfiltered water in 1908-09, and Moscow, which takes only the effluent from English sand-filters, so far as regards the number of cholera cases in these years, is referred to in the Imperial Reports.

On the whole there seems to be good grounds for the belief that cholera becomes epidemic wherever the service water is exposed to contamination with its germs, and it is merely sporadic and occasional when pure water is distributed to the community.

Typhoid from Contaminated Supplies.—Not less certain is it that typhoid fever owes much of its prevalence to unsound water-supplies. Looking over the health statistics of forty of the chief cities of Europe and America, one cannot fail to be struck with the correlation between the death-rate from typhoid and the character of the water provided. Towns which enjoy the benefit of water beyond the reach of contamination, as Munich, Frankfort, Copenhagen, show a mortality from this disease well below the average; while others, like Baltimore, Venice, Minneapolis, Worcester, St. Louis, have had bad records. According to Fuertes ("Water and Public

Health "), the death-rate from typhoid ranges in Europe and America between 6 and 33 per 100,000 in urban populations provided with water from underground sources. The average would thus be about 18. He also makes out that the average mortality in towns supplied with filtered surface water is only 12 per 100,000, but more recent investigations lead Whipple to the conclusion that it is higher, and nearer to the figure for the first-named series of towns.

Local conditions have so much to do with the health of a community that it is difficult to strike averages to the exclusion of typhoid cases that are known to have nothing to do with the quality of the water. But when we find that Munich, Dresden, La Haye, Berlin, Rotterdam, and many other towns, have death-rates from typhoid that are often well under 10 per 100,000, we may safely conclude that a mortality in excess of that figure is indebted to the water-supply for an increment that might be cut down. The high death-rates from typhoid that prevailed in many American cities, and in not a few British and Continental centres, in recent years, most of them with an environment hygienically as good as that of Rotterdam, represent the price paid for unwholesome water. And the price thus indirectly paid by a community is not a trifle.

Loss to Communities from Typhoid.—Dr. Weldert (*Wasser und Abwasser*, Bd. i., Nr. 2) has calculated that a town with a mortality from typhoid 23 over an assumed mean of 20 per 100,000 pays an additional £5 15s. for every 1,000 m³. of water used (approximately, 5d. per 100 gallons). Dr. Weldert bases his calculation on the ordinarily assessed value of a human life, and on the compensation due for time lost through illness, and he thus deduces that a town of 100,000, with a death roll of 43 per annum from typhoid, pays £23,000 yearly for unscientific treatment of the service water—that is to say, a sum far in excess of the upkeep costs.

We see here a complete justification, even from an economical point of view, of the large expenditure that has led to the improvement of so many purification plants in recent times. Perfecting of the filtration has been attended by distinct reduction of the typhoid mortality in almost every instance. In some cases the disease has all but disappeared. London, Paris, Moscow, are outstanding examples of the influence of

thorough treatment of service water on the inroads of this pest, but perhaps the most striking and instructive case is that of Cherbourg.

Disappearance of Typhoid at Cherbourg due to Improved Purification.—Prior to the year 1907, the town of Cherbourg was supplied from the River Divette, the water being passed through Maignen filters, which did not give efficient bacterial purification. At the same time the neighbouring arsenal, with a population of 8,000, made use of unfiltered Divette water. The river is extremely liable to pollution from farms within its basin. In the autumn of 1898 the town was visited by an epidemic of typhoid, which claimed twenty-five victims among the civil population (32,000 souls), and sixty-three from the garrison at the arsenal. Relatively speaking, the mortality among those using crude water was ten times as great as with those who were supplied with filtered water, unsatisfactory though the filters were. In 1908 typhoid paid a second visit to arsenal and town. By this time the civil population had wisely installed the Puech-Chabal filters, while the military authorities still clung to the crude and dangerous water of the Divette. On this occasion the epidemic claimed a toll of fifty-four victims from the arsenal, while the civil population was almost wholly spared. Only one death occurred, three months after the disease broke out among the military. The Puech-Chabal system of filtration had thus rendered the civilian immune from the malady. The contrast between the two divisions of Cherbourg, both supplied from the same source, depending on unfiltered water in the one case, and protecting public health by a thoroughly approved method of purification, requires no underlining. That the lives of most of the military who were stricken in the winter of 1908-09 could have been preserved is evidenced by the fact that there exists a military depot in the centre of the town, with a large detachment of soldiers in residence. Among these there were no fatal cases. Their supply came from the Puech-Chabal filters.

The purity of the Paris supply has been receiving great attention during the last decade, and the decrease of typhoid cases is remarkable. For the five years, 1890-1894, the average mortality from this disease was 27 per 100,000. From 1901 to 1904 it had sunk to 12·2, and between 1905 and 1908 the average

fell to 9·2. The statistics for London show an equally favourable record of typhoid mortality. The average from 1890 to 1894 was 15 deaths per 100,000. In 1896 the mortality was as high as 38. Very different is the record for the years 1905-1907. The average for these three years was only 5 per 100,000. The average for the ten years preceding 1905 had been 12. Thus there was a fall of 7. This is equivalent to the conservation of 330 lives in London per annum, not to mention the much larger number of cases that do not end fatally, and which are not here taken into account. In Berlin the fatal cases of typhoid from 1880 to 1893 amounted to several hundreds annually, the population being then about 1,500,000. The mortality from the same cause for the ten years ending 1909 has averaged 64 only, though there has been an increase of 500,000 inhabitants.

The use of water contaminated with sewage must always be reckoned dangerous, although epidemics will not follow unless the specific germs are actually present when the water is distributed to the consumer. Instances are so numerous in which communities have used polluted water for months without being attacked by this disease, that one may justly reason that immunity resulted from the absence of the prime cause. The history of water-borne epidemics throws light on the matter. The outbreak in general loses no time in taking a firm grasp of the community, thus showing that the seeds have been well distributed. Investigations being then set on foot to discover whether the dejecta of sufferers from the malady have found access to the water, it rarely happens that absolute proof of the intrusion of infected dejecta can be furnished. More frequently there is presumptive evidence that the supply has been contaminated either from actual sufferers or from "carriers." With regard to the epidemic at Nunney (Report of Local Government Board on the outbreak of enteric fever at Nunney), and the recurring and often virulent outbreaks at Belfast between 1895 and 1902 (see Professor Lorrain Smith's pamphlet, "The Occurrence of Typhoid in Belfast"), there is positive evidence that typhoid germs had easy access to the supply. Nor can there be much doubt that direct infection of the service water led to outbreaks at Lincoln, Cherbourg, Metz (see *Water*, vol. v., p. 368).

It is significant that cities using unfiltered river water have

abnormal death-rates from typhoid. The average rate for Washington, Pittsburg, Louisville, before 1901, reached 76. On the other hand, the average rate for London, Amsterdam, Paris, Edinburgh, Hamburg, Berlin, Copenhagen, Rotterdam, Breslau, and Zurich, which are supplied with carefully filtered water, is at present well under 10 per 100,000 per annum. Bearing in mind that typhoid infection is carried by milk and other foods that have been in contact with "carriers," convalescents or sufferers, and that it may also be spread by wind, we may infer that in these great cities water-borne typhoid has been practically eliminated by the efficient filtration adopted. The better sanitary conditions under which communities now live, more scientific drainage, more careful cleansing of streets and tenements, and improved education of the masses, have contributed to restrict the inroads of all epidemics. It is the province of these agencies to maintain the struggle against the ravages of typhoid and to hunt it out of its coverts, so that we may look forward to a time when its visitations will be as unfamiliar as those of Asiatic cholera.

CHAPTER XIV

RECENT ADVANCES IN STERILIZATION

The Excess Lime Sterilization Process.

Objections have been raised against the usual processes of sterilization, some of which are real, others fanciful. Ozone treatment is somewhat costly, and the capital outlay is considerable. Chlorination is supposed to leave a taste described as "mawkish" or chlorinous, which is appreciable to some consumers and not to others. No fault can be found with the use of ultra-violet rays on the ground of residual taste, and the only reasonable argument against this method of sterilization would seem to be that it has not been sufficiently tested by a continuous application to a large supply.

Sterilization by excess lime, as proposed by Dr. Houston, appears to meet every possible objection. It can be carried out at a low cost (3s. to 15s. per million gallons, according to the hardness of the water), the capital charge is very moderate, and there is no residue which can have any injurious effect on the quality of the water as regards household or industrial uses. On the contrary, the result of this treatment, so far as concerns the mineral ingredients in the water, may be regarded as quite beneficial. Applied to hard waters, it softens them, and with soft waters it produces some degree of hardening.

Although it has been known for some time that lime is a powerful bactericide, the conception of a system by which public supplies might be sterilized by lime, and the description of a procedure to be adopted according to the nature of the water, are entirely due to Dr. Houston. He has shown that with soft waters a dose of 1 part of lime per 10,000 to 1 per 20,000 exterminates all bacteria in from five to twenty-four

hours, and smaller quantities, as 1 in 50,000, suffice for very soft waters, given a full period of twenty-four hours.

Dealing now with hard waters containing bicarbonate of lime in solution, the first effect of the added lime is to precipitate the bicarbonate, and the lime used up in this chemical action is without bactericidal power. Natural waters also contain free carbonic acid in solution, and this also enters into combination with a portion of the lime. In general it may be said that each degree of hardness requires for softening from 7½ to 10 pounds of quicklime per 100,000 gallons. The smaller figure (7½ pounds) is more applicable where a large reduction of hardness is contemplated, because the free carbonic acid is a more or less constant quantity, and does not increase in amount with the amount of salts dissolved. We have to understand that in the case of a hard water sterilization is effected by adding an excess of lime over and above what would be required to remove the temporary hardness (due to bicarbonate of lime and magnesia) plus the free carbonic acid. The excess should be, generally speaking, equal to the sterilizing dose required for a very soft water referred to above. One part in 20,000 means 50 pounds of quicklime per 100,000 gallons, since a gallon of water weighs 10 pounds.

Thames water has about 17 degrees of temporary hardness on an average, and this necessitates the addition of 127½ ($7\frac{1}{2} \times 17$) pounds of lime for its removal. By adding quicklime in the proportion of 1 in 5,000—*i.e.*, 200 pounds per 100,000 gallons—Dr. Houston obtained sterilization in five to twenty-four hours. The excess of lime here was probably rather more than 50 pounds. The actual bactericidal dose was estimated very simply by ascertaining the amount of caustic lime left in the water after being added in the proportion stated (1 in 5,000). The estimate was that 1 part of quicklime in 14,300 (70 pounds per 100,000) is sufficient to destroy *Bacillus coli*, and inferentially all other microbes of a dangerous type. That this small dose of quicklime was effective was proved by reinoculating the water with sewage and setting it aside for the prescribed time. Sterilization was found to have taken place.

The very soft water of Loch Katrine, when inoculated with sewage, is sterilized with 25 pounds per 100,000 gallons in twenty-four hours, and even smaller doses are sufficient when

applied to water that has first been softened by boiling, then cooled and inoculated.

Removal of Excess Lime.—In the case of waters naturally soft the amount of excess lime is small, and various simple arrangements might be made for neutralizing the alkali remaining, according to circumstances. By exposing the treated water to the air in a series of cascades, or by spraying over a bed of clinker or coarse gravel, the carbonic acid of the air would convert the lime into chalk. The same result would follow from passing carbonic gas into the water, though this procedure would be rather more expensive. The soft water would finally be hardened 2 or 3 degrees.

For hard waters Dr. Houston makes the happy suggestion that three-fourths of the water or thereby should be lime-sterilized, and afterwards mixed with one-fourth volume of unlimed water which has been previously rendered "safe" by storage or sterilized by chlorine, ozone, ultra-violet rays, or otherwise. Of course, any other ratio as between the limed water and the portion sterilized might be adopted. Bearing in mind the double purpose of sterilization and reduction of hardness, the ratio suggested works to the best advantage, and in the case of Thames water the hardness is reduced to 7·5 degrees.

Cost of this Process.—Capital outlay would be required to meet the cost of constructing mixing tanks and sterilizing basins, with all the necessary connections. Further, with soft waters there would be additional arrangements for removing the excess lime. As regards working expenses, the cost of lime for 100,000 gallons with 10 degrees of temporary hardness would be, approximately, 1s. To this must be added the wages of an attendant for a part of the day. All things considered, there is no doubt that this method of sterilization would be one of the cheapest that has been proposed up to the present. In his Eighth Report of Research Work, Dr. Houston does not minimize the possible difficulties that might be encountered in grafting this sterilization scheme upon an installation already established; but such difficulties present themselves no matter what form the mode of sterilizing may take.

The advantages of the excess lime method are summed up in the report just mentioned:

(1) The treatment is innocuous. (2) It renders the supply absolutely safe. (3) It softens hard waters, and thus effects a saving of soap and fuel. It hardens soft waters to a slight extent. (4) It is well adapted for dealing with flood water. (5) It virtually increases the yield of the source, because water may be abstracted (as from a river in spate) at any time. (6) It may obviate the necessity of enlarging reservoirs, and of obtaining additional, or even altogether new, supplies. (7) It is applicable to any water that is being used for public supply, and, in general, for any source that might reasonably be made use of.

EXPERIMENTS IN WATER PURIFICATION AT MARSEILLES.

Being in urgent need of a system of purification to deal with its germ-infected water, the city of Marseilles undertook in 1910 a comprehensive series of experiments in order to compare the efficiencies of various types of purifying and sterilizing apparatus. Experimental plants were therefore laid down in accordance with seven different processes, and each was maintained on trial for a period of three months' continuous working. The volume of water dealt with by each type was arranged to be not less than 44,000 gallons per day, so that the equipment, conditions of working, and even the current expenses, were readily comparable with those of any larger installation of the kind which the city might eventually select for its use.

A Municipal Commission took charge of the work of supervision, the owners of the different processes undertaking all the outlays in connection with the installation of plant and with the daily management of the same. The city of Marseilles has been supplied for many years from a canal fed by the River Durance, which is by no means free from contamination. The canal traverses cultivated lands and passes many villages, and is constantly subject to pollution from sewage, factory effluents, and other sources, including the dead bodies of animals. In its passage along the canal the water gradually becomes more and more infected. The bacterial content of the service water is 5,000 per cm^3., and *B. coli* is always present. The public health of Marseilles leaves much to be desired. The mortality from typhoid fever

is four times greater than in Paris, and is, in fact, about the highest in France.

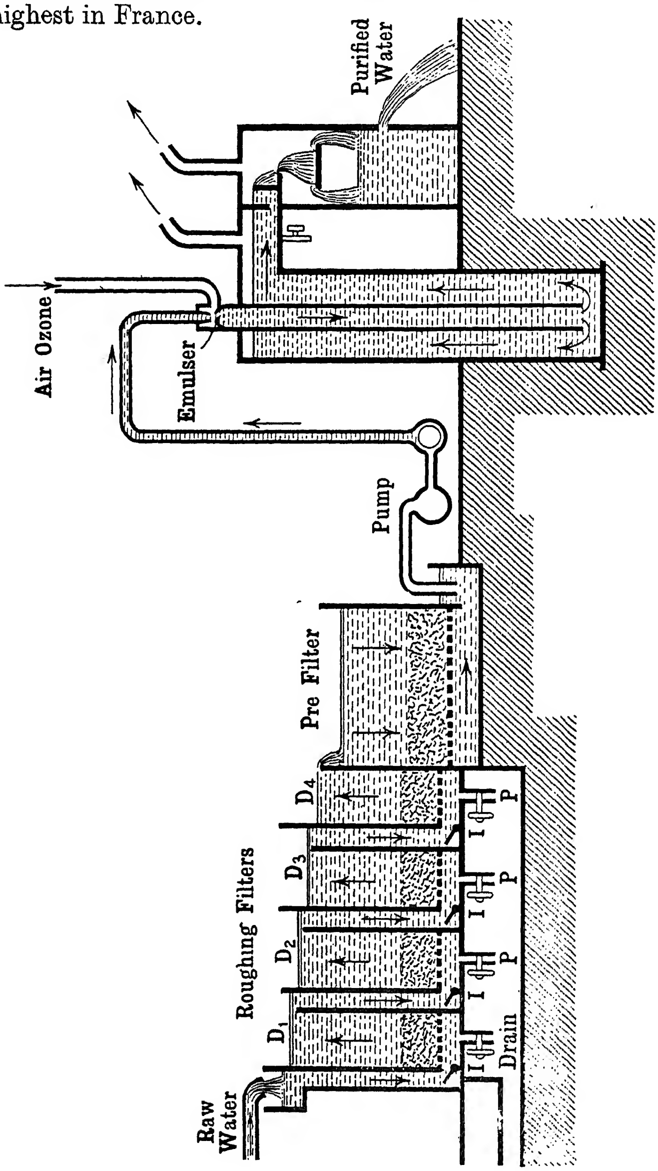


FIG. 97.—GENERAL VIEW OF THE OTTO PROCESS AT MARSEILLES.

Precipitants were employed in two of the processes—viz., Desrumaux and Duyk—the former using sulphate of alumina alone, the latter sulphate of alumina with the addition of a

little ferric sulphate and chloride of lime. Treatment with alumina followed by decantation, rough filtration, and subsequent passage of the water through 3 feet of fine sand, was sufficient to produce clarification without modifying sensibly the mineral content. But from a bacteriological point of view the purification was not entirely satisfactory, as *B. coli* was rarely absent from 100 cm^3., and the total count of germs per cm^3. reached several hundreds. The degree of purification in this respect was 93 per cent.

These experiments with the Desrumaux system showed that a dose of 3 to 4 grains of alumina per gallon left no residue of alumina in the filtered water. For every 30 parts of alumina added, 18 parts of sulphate of lime are formed by chemical reaction with the carbonate of lime actually present in the raw water.

According to the Duyk system, a dose of 2 grains, or thereby, of sulphate of alumina mixed with a small proportion of iron oxide and with 0·3 grain of chloride of lime was added to the crude water. Subsidence was then permitted for one to two hours, when the clarified water was passed through a bed of gravel, and finally filtered through graded quartz. Adequate arrangements were made for cleansing the latter with filtered water two or three times per day. On leaving the quartz filter the effluent was led to a sequence of cascades in order to dispel the residues of chlorine. Chemically and bacteriologically the Duyk process was found to produce satisfactory results, all *B. coli* being exterminated, and the germ content being reduced to an average of 200 per cm^3. One objection only was upheld—namely, that there remained faint traces of chloride of lime in the service water. The chlorinous odour was always more or less perceptible, while the water gave the well-known reaction with potassium iodide and starch which indicates the presence of free chlorine.

Purification by Ozone.—The Siemens-De Frise apparatus has already been referred to at p. 210 *et seq.*, and the installation which the company set up at Marseilles differed only in details from that already described. Preliminary clarification of the canal water was accomplished in one or other of two ways, and both were found to be satisfactory. According to the first method, sulphate of alumina to the amount of 1 grain per gallon was added in a precipitating chamber, from which

the water proceeded to a filter of coarse sand, the granules averaging $\frac{1}{12}$ inch. This filter could be cleaned by a reverse current of clarified water. The other plan consisted in bringing the raw water to a sedimenting chamber of special shape, tapering below, and decanting without coagulants. Filtration followed, and in this case the area of the bed was much larger than that employed after the alumina treatment. Still, the rate of flow might be described as rapid as compared with the ordinary slow sand filter. Cleaning was effected once a week by means of a simple device. Mounted on a vertical pivot immediately above the sand were two horizontal arms ; these were tubes leading to drainage, and each was pierced along its length with small openings. To clean the filter the ordinary outlet was closed, the scour valve opened, and the arms rotated. The water escaping by the perforations under the pressure of the "head" still remaining in the filter carried with it the slime and mud deposited on the surface. The operation was repeated once in eight hours.

After clarification the water arrived at the base of the sterilizer (a vertical cylinder 30 feet high), and travelled upwards, accompanied with a suitable charge of ozonized air. Contact with the ozone was maintained for about five minutes, and intimate mixing was secured by means of the perforated screens referred to at p. 212.

The electric current to the ozonizer (Fig. 53) was an alternating one of 150 periods, and this was stepped up to a tension of from 7,000 to 10,000 volts. The ozonized air contained 2 grammes of ozone per cubic metre, and 0·8 gramme of ozone was absorbed by 1 cubic metre (220 gallons) of water. One kilowatt-hour produced 48 grammes of ozone, which was sufficient to deal with 10,000 gallons.

The results of the Siemens - De Frise system were wholly satisfactory. The effluent was limpid, well aerated, and entirely free from *B. coli*, while only five to ten harmless types of bacteria per $cm.^3$ remained.

THE OTTO PROCESS (COMPAGNIE GÉNÉRALE D'OZONE).

The clarification of the canal water was in this case effected by a series of roughing filters of coarse quartz ($\frac{1}{6}$ to $\frac{1}{8}$ inch) in beds 20 inches deep, followed by prefilters of fine sand. The

raw water passed through the roughing filters from below upwards. Twice a week they were cleaned by a reverse current from above. The prefilter required scraping or raking once a month, and washing to scour valves situated at the level of the sand surface.

On leaving the prefilter (see Fig. 97), the clarified water was pumped to an "emulser" (p. 222), in which the proper charge of ozonized air was intermingled with it. Descending through the sterilizer in a central tube, the mixture of air, ozone, and water ascended towards the outlet, and reached the cascades after delivering up the residual air and ozone to pipes leading to the ozonizer. The ozonizer has been described at p. 222. The distance between the plates was $\frac{7}{8}$ inch, and the dried and cooled air entered laterally and made exit by a central orifice.

The electric current was one of 500 periods transformed to a high voltage. The production of ozone was about 40 grammes per kilowatt-hour. Each cubic metre of water received 0·75 gramme.

The results were parallel to those obtained by Siemens-De Frise. The effluent was highly transparent and practically sterile.

In short, the Commission had no hesitation in expressing confidence in both the processes in which ozone was employed. The treated water satisfied every condition as regards its suitability for the supply of Marseilles.

SYSTEM PUECH-CHABAL, WITH STERILIZATION BY ULTRA-VIOLET RAYS.

Here the roughing filters were of the usual type described at p. 134. They were arranged in three steps. Cleansing was carried out with the help of compressed air and a small amount of wash water. The first *dégrossisseur* required attention twice a month at least, the others less frequently. Following these was a prefilter consisting of 20 inches of sand resting on $2\frac{1}{2}$ inches of gravel. Four prefilters were ranged in parallel. The water was then collected in a suitable basin, from which conduits led to three different types of treatment by which the final process of purification was to be carried out. There were respectively—

1. Puech-Chabal finishing filter.
2. Non-submerged sand filter.
3. Sterilization by ultra-violet rays.

The first of these was of the kind described at p. 136. The results were on the whole satisfactory, but occasionally *B. coli* was detected in volumes of 100 cm^3. For days in succession, however, no *B. coli* could be detected. The average number of germs in the effluent was 168 for the whole month of July, a reduction of 97 per cent. The water was also markedly transparent. The non-submerged finishing filter also consisted of a bed of fine sand, about 3 feet deep, over which water coming from the prefilters was sprayed (p. 145). Unfortunately, after having given good results for two or three months, the sand became clogged with vegetable growths. Probably the grade of sand was too fine. The stoppage was not due to deposits of lime or other mineral matter.

On the whole, the non-submerged filter did not give so good bacteriological results as the submerged, *B. coli* occurring more frequently in the effluent, and more germs of all kinds surviving the treatment.

The third method consisted of sterilization of the prefiltered water by ultra-violet rays from a Westinghouse-Cooper-Hewitt

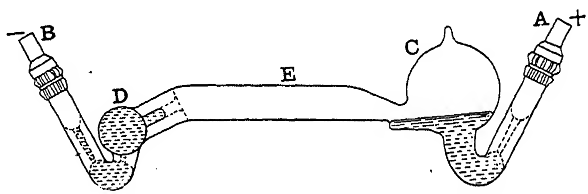


FIG. 98.—WESTINGHOUSE-COOPER-HEWITT 220-VOLT LAMP.

A, B, Electrodes ; C, D, mercury reservoirs ; E, transparent tube of quartz.

lamp. This lamp consists of a short tube of transparent quartz, with a small depression or reservoir at each end containing mercury (Fig. 98). The electrodes dip into the mercury. The tube is exhausted of air so that the space between the electrodes is occupied by vapour of mercury. To start the current it is necessary to tip the lamp slightly, so that a thread of mercury extends from end to end. This warms the vapour of mercury, and the lamp can at once be set in its normal position.

The light emitted is specially rich in ultra-violet rays. Researches were made by M. Roux, Director of the Pasteur Institute, and by other experts, in 1909, to determine the bacteri-

cidal action of ultra-violet rays with special reference to *B. coli*, *B. typhosus*, *Vibrio choleræ*, *B. dysentericus*. It was found that the destructive action of the lamp upon bacteria had a well-defined range both as regards distance and time required for sterilization. A lamp worked with a current of 3 ampères at 220 volts destroyed pathogenic germs within a radius of 2½ inches in two seconds' time. Investigations made at the Academy of Sciences showed that when the lamp was suspended over a stream of infected water 12 inches deep, a

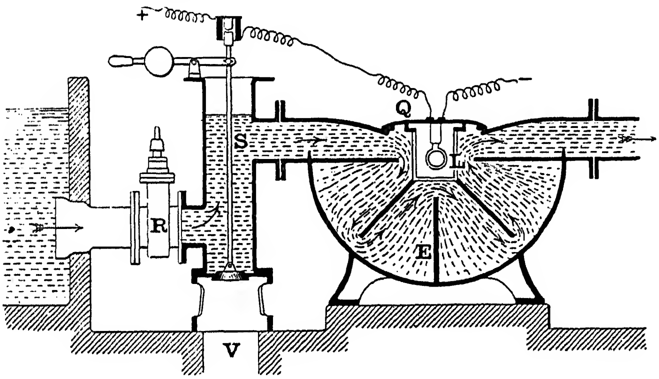


FIG. 99.—PUECH-CHABAL STERILIZER AT MARSEILLES.
R, Filtered water inlet ; S, Release valve ; L, Mercury lamp ; Q, Box containing lamp ; E, Baffle plates ; V, Drain.

certain number of bacteria escaped. A second lamp was therefore put in position at a short distance downstream, and the effect of this was to complete the sterilization.

Accordingly, an apparatus has been introduced by MM. Puech-Chabal (Fig. 99) in which the water is directed by baffle-plates to approach and retreat from the lamp three times in succession. This was put in operation at Marseilles to sterilize the prefiltered water. It worked continuously night and day for two months, and gave perfect results. Only three or four germs of a harmless type survived, but no *B. coli* were found in quantities up to 100 cm^3.

The electrical energy expended was 26 watt-hours per cubic metre, or 12 B.T.U. per 100,000 gallons.

The mercury lamp has a very long life, which may extend to several thousand hours. Should, however, an accident occur to cause the failure of the light, the supply water is instantly cut

off and an alarm-bell rung. It has been asserted that the lamp becomes enfeebled by long working, and, further, that some peroxide of hydrogen is formed in the water. There does not seem to be any good ground for either of these objections.

There appears to be an optimum temperature at which the lamp works most satisfactorily, and for this reason there is an advantage in enclosing it in an air chamber (Fig. 99 Q), and allowing the radiation to act on the water through quartz glass windows.

JERSEY CITY STERILIZATION PLANT WITH HYPOCHLORITE.

The Jersey City water-supply comes from the Rockaway River, and is stored in the Boonton reservoir (capacity, 8,500 million U.S. gallons), from which the 40 million gallons daily supply are drawn. In 1908 it was found that owing to floods the city water was occasionally of "doubtful" quality, containing as it did large numbers of bacteria and *B. coli* detectable in small volumes. It was not believed that the water was sewage-polluted, but that the washings of manured fields, roads, etc., found access to the supply could not be doubted. The question of sand-filtration was discussed, but the great expenditure involved did not appear to be warranted, seeing that the stored water contained very little matter in suspension. The advice of Dr. Leal to instal a sterilizing plant was followed, bleaching lime being the agent employed.

The following points were made out with regard to the action of water on bleaching lime, and the final decomposition and destination of the chemical:

1. On being added to water, bleaching lime splits up into chloride and hypochlorite of lime. The former remains inert and harmless, while the latter is further decomposed by the carbonic acid in the water. Carbonate of lime and hypochlorous acid result. The hypochlorous acid ($HClO$) then parts with its oxygen to oxidizable matter, as nitrites, organic substances, and bacteria. The hydrochloric acid (HCl) left after oxygen splits off unites with any carbonate present, and forms chlorides.

2. The active agent is thus the nascent oxygen, and no free hypochlorous acid is left in the water in the presence of oxidizable material.

3. No free chlorine is introduced into the water, according to Dr. Leal, by any of the reactions.

The results of the treatment have been that with 0·2 part of available chlorine per million (about 5 pounds of bleaching lime per million gallons) the service water has been rendered practically sterile. The cost of material is 3½d. per 1,000,000 U.S. gallons. Chemically the water is little altered, only a slight increase of hardness and a trifling reduction of carbonic acid being observed.

When the reservoir is receiving very heavy floods, the dose is increased to 0·35 part per million.

Mr. G. W. Fuller in his address to the Convention of the American Water Works Association in 1909 claimed that the action of bleaching lime was exactly similar to that of ozone. In both cases nascent oxygen is the bactericide. Like ozone, hypochlorite exercises a selective action, as it attacks pathogenic bacteria more readily than others. He believed that germs embedded in minute fragments of decaying vegetable matter would occasionally escape, more especially if they happened to be in the spore condition. Fortunately, the dangerous bacteria which occur in water do not form spores, with the possible exception of anthrax.

The Sterilizing Plant. — It being the purpose of the sterilizing apparatus to produce a ½ per cent. solution (5 pounds per 1,000 pounds of water) of bleaching lime, and to run this at a uniform rate into the mains issuing from the reservoir, so as to provide the dose previously determined, the following arrangements were made. Three concrete cylinders, 11 feet deep and of like diameter, form the solution tanks. Into each is fixed a mixing tank, 6 feet in diameter and 3 feet deep, to receive the daily charge of bleaching lime. Water is supplied by two 3-inch pipes, and stirring devices are provided, actuated from turbines in the mains. In the centre of each mixing tank is an overflow pipe, rising 18 inches from the bottom, to convey the bleach and water into the solution tanks below. All the tanks are provided with blow-off pipes for removing sludge.

The daily charge of bleaching lime is calculated by noting the depth of water in the solution tank and finding how much bleach is necessary for the volume of water required to fill up

the tank. From the solution tanks the liquid is pumped to two "orifice" chambers, which are always kept full and overflowing, the surplus being passed back to the solution tanks. The object of keeping the mixing chamber full is to obtain a uniform head and flow in the pipes distributing the sterilizing fluid to the mains. Only one set of tanks is put in use at a time, as the whole installation is planned in duplicate.

Four 48-inch mains lead from Boonton reservoir to the aqueduct, and into these the chlorinated fluid is fed by perforated grids placed at the mouth of each. The grids are merely inch pipes drilled with twelve ¼-inch openings, and they are fed from the orifice chamber by a 3-inch pipe. On this pipe is a regulating device with manometer screw, by means of which the prescribed volume to be applied to the water can be calculated to a nicety.

The effect of the treatment on the service water has been fully investigated, the most important point being that there is no residue of free chlorine, no taste or smell to indicate that a chemical has been added. The water does not attack the iron pipes, as Professor Cornwall was able to show from the fact that there is no more iron in the water at Jersey City than at the reservoir. There is a slight decrease of free carbonic acid, as might have been expected, as well as a minute increase of chloride of lime.

Under existing circumstances the total cost of the treatment per million U.S. gallons is as follows :

One extra operator - - -	3½d.
Bleaching lime and laboratory expenses	3½d.

—being a total of 7d.

It is further calculated that if sodium hypochlorite, electrolytically prepared by current generated from turbines in the mains, were employed instead of bleaching lime, the cost would be reduced to 6d. per million U.S. gallons. The use of this chemical would do away with the slight trace of chloride of lime left in the treated water, as only sodium chloride—that is, common salt—is formed by its decomposition.

Sterilizing Plant at Newport, R.I., U.S.A.

The daily supply at Newport amounts to 6,000,000 gallons, collected from grounds which are mostly owned by the company. The water is, however, discoloured by vegetable matter as a rule, and it often has an odour which is far from agreeable. The micro-organisms found in it include desmids, diatoms, protozoa, and about 300 bacteria of various kinds per cm^3. The purification works are devised to remove colour and odour and to destroy the germs.

The plant has been designed in such a way that the method of operation can be varied at will, and permits of sedimentation with or without coagulants, and of sterilization before or after filtration. The filters are those of the New York Continental Jewell Filtration Company.

The objectionable odours are got rid of by aeration. For this purpose two large concrete boxes are provided with converging slabs, on which are laid certain iron sections 2 inches square. These are ridged in such a way that when bolted together the whole presents a series of channels abutting one against the other, and forcing the incoming water to take a tortuous and tangential course, and form at the same time a multitude of little cascades down a slope of several feet.

The water is next conveyed to the settling basins for treatment with alumina, and after filtration it is sterilized with bleaching lime. The coagulant is prepared in a building which contains two alumina and two hypochlorite tanks. The alumina is dissolved by spraying, and a 2 per cent. solution is made and well stirred in the tank. It is led to an orifice chamber, from which it is measured into the pipes leading to the settling basins. The bleaching lime is first mixed with some water in a covered porcelain-lined box, and then conducted to the storage tank, in which it is kept in agitation. It is applied to the filtered water because it was found that its effect was entirely lost when introduced into the raw water, even in doses considerably larger than those usually employed. The result of this treatment is that clear water with practically no bacteria is provided for the consumers. The ordinary proportion of coagulant is 1 grain per U.S. gallon, and of bleaching lime 0·5 part per million.

A sterilization plant with hypochlorite has now been con-

structed for Kansas City, Mo., which is supplied from the Missouri River. From 8 to 12½ pounds of bleaching-lime are required per 1,000,000 U.S. gallons, and the cost of labour and materials is about 1s. 3d. for this quantity of water. As usual, the mixing and solution tanks are built of concrete. All bearings and stirring or disintegrating devices that come in contact with the bleaching solution are made of bronze, as this metal soon becomes covered with a protective coat of carbonate and oxychloride. At nearly 300 water-supplies in the United States the use of hypochlorite is now established. In some cases it is employed in conjunction with sedimentation, in others with filtration, and occasionally it is the only means of purification. The results have not been satisfactory in every instance, owing, as a rule, to faulty construction and unskilful management. But at the larger installations, as New Jersey, the Associated Water Companies of North New Jersey, Newport, Cincinnati, Kansas, the treatment has fulfilled all expectations. According to Mr. S. Y. High,* sterilization by hypochlorite cheapens the installation costs of a purifying plant by doing away with the necessity for slow sand filtration, the desired results being obtained more rapidly and within a much smaller area by sedimentation, and prefiltration by mechanical filters.

THE CANDY PATENT DE CHLOR FILTERING PLANT.

The De Chlor plant has been designed to apply automatically to water any prearranged quantity of hypochlorite, and to remove, by passing the treated water through an insoluble dechlorinating medium, the slight excess of sterilizing agent which it is essential to employ in order to eliminate bacteria. The apparatus provides that the water shall remain for a sufficient time in contact with the sterilizing agent.

The De Chlor process was adopted by the Reading Corporation in 1910. The water drawn from the River Kennet, and containing 4,000 bacteria per cm^3., is first prefiltered, and then pumped continuously night and day through the De Chlor filter into the service reservoir. This filter is a cylinder of 8 feet diameter and 17 feet in height. On the floor within rests a filter formed of separate layers of graded sand or

* Proceedings of the American Waterworks Association, 1912.

ilica and a granulated dechlorinating material which has he power of removing all taste and odour of chlorine from

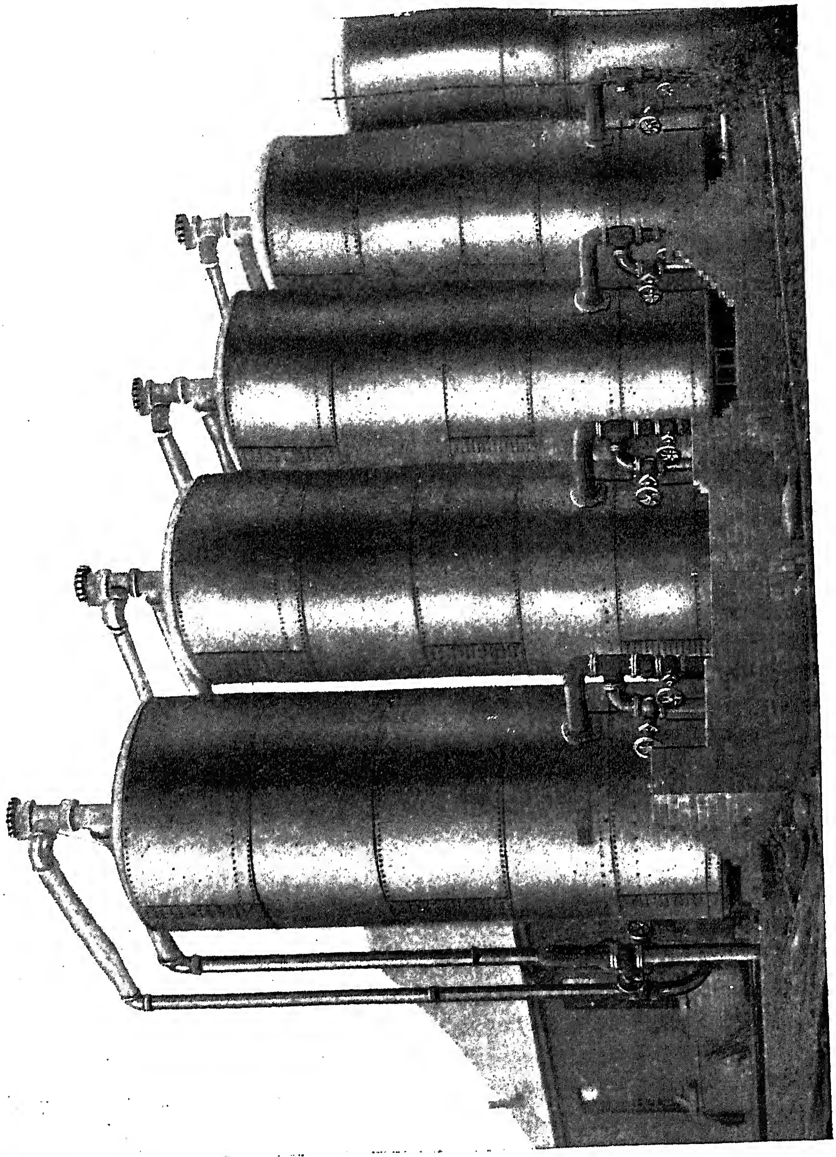


FIG. 100.—CANDY DE CHLOR FILTERING PLANT.

;he water. The filter occupies a depth of about 5 feet. It s not a filter properly speaking, because its function is to

destroy any residues of the hypochlorite. It requires cleansing by a reversed flow of water once a week, the operation lasting twenty minutes. The sediment which accumulates is therefore trifling in amount, and the wash-water is only 0·1 per cent. of the consumption.

The sterilizing liquid is prepared in mixing and settling tanks, which are provided in duplicate. A weighed amount of chloride of lime is first mixed with water to form a thick milk, and then led to the settling tank. After a period of quiescence it is allowed to flow through a regulator, where a measured quantity of water is added. Being now at standard strength it is ready to be lifted by the pump into the main inlet, which brings the water to the dome of the cylinder. The waterworks engineer, Mr. Leslie C. Walker, reports that with this arrangement there is no difficulty in regulating the dose to 1 part of available chlorine per 1,000,000 parts of water. The Candy Filter Company have, however, patented a simple and automatic device for injecting a measured quantity of sterilizing fluid into a water-main. This is the "hydro-pneumatic injector," which, in conjunction with a venturi tube, accurately proportions the dose to the amount of water dealt with. The absence of moving parts in dealing with an active chemical is a manifest advantage. The prefiltered water, after receiving the hypochlorite, passes into the cylinder from above, and falls on a tray to secure uniform distribution. Beneath, the water stands to a depth of about 10 feet over the filtering media already mentioned. The rate of flow from the filter is such that the water takes thirty minutes to traverse the distance of 10 feet between the dome and the bed of silica.

Ample time is therefore given to the hypochlorite to act upon bacteria. The examination of the treated water shows that the bacteriological results are most satisfactory, no *B. coli* having been found in volumes of 100 cm^3., although they are recognizable in 10 cm^3. of prefiltered water on all occasions, and often in smaller volumes. The number of germs which persist after the De Chlor process is very small, and they are of a harmless type. The service water on being tested for free chlorine gives negative results, and no complaint on this ground has been made by consumers.

The rate of filtration in the De Chlor filter is 280 inches per hour, or about eighty times that of slow sand filters. The cost of bleaching lime is 1s. 10d. per 1,000,000 gallons. The

following figures given by the waterworks engineer to the Reading Corporation show the actual cost of the De Chlor system after three years' working:

Chemicals	£35	2	0
Carbon and renewals	18	0	0
Interest and repayment	200	0	0
	£253	2	0

This works out at ·17d. per 1,000 gallons of water treated. The installation of the De Chlor plant did not necessitate any increase in the staff of workmen.

A similar sterilizing plant has lately been adopted at Truro, and also at Egham (see p. 144), the latter dealing with 3,000,000 gallons daily. At both places results quite as satisfactory as at Reading have been obtained.

DOUBLE FILTRATION BY CANDY MECHANICAL FILTERS.

The Candy Patent Compound Filter.—In this filter there are *two* permanently separated filtering layers or beds. The upper bed, termed the "prefilter," is a comparatively coarse one, and is supported upon a perforated false floor; the lower bed is composed of fine sand or silica, and there is a space of about 2 feet between the said false floor and the surface of the fine sand bed below it, which also rests upon a false floor furnished with gun-metal or porcelain nozzles. There is therefore a mechanical filter *plus* a combined prefilter; so that the water undergoes a double and progressive process of filtration. The coarser particles of suspended matter in the water are eliminated in the comparatively coarse prefilter, thus preventing them from reaching the fine filter. It is claimed that in the roughing filter an aggregating or "snowball" action takes place, by which the condition of the finest particles is altered and their power of sealing the sand is reduced. The makers find that with this arrangement the interval between cleanings is very much increased.

In the washing process, both the fine bed and the coarse or prefilter bed are cleaned at the same time and at the same operation. The fine bed is cleaned by a reversed flow of filtered water, passing upwards through the bed and so loosening the sand, acting in combination with powerful streams of water issuing under pressure from a scour arm that is slowly rotated just above the level of the sand. These streams of water, discharged from gun-metal jets at a velocity

of from 40 to 50 feet per second, penetrate into the sand, and, in conjunction with the upward-flow water issuing from the nozzles in the floor, carry away the suspended matter that has been freed by the intensive scouring action produced. The scour arm turns easily, and engine power is unnecessary, though it may be utilized if available.

A second scour arm, working in conjunction with the scour arm previously referred to, discharges streams of water on the top of the prefilter, which wash the coarse granules free from adhesive matters. The open character of the bed favours the action of the wash water. A sectional perspective view of this filter is shown in Fig. 101.

While the filter is being cleansed, valve A is closed, valves B, E, and D, are opened, and the handle F is rotated. An air valve, not shown in the illustration, admits air to the upper part of the filter during its cleansing, so that immediately the valve E is open the water in the top of the filter rushes down through the prefilter, giving it a preliminary flushing, the water-level within the filter being then as shown in the illustration. The prefilter H is washed by the spray jets of water issuing from the upper rotating scour arm; while the fine sand-bed J is washed by the streams of water issuing from the jets in the lower rotating scour arm, in combination with an upward flow through the bed of filtered water entering through the valve B. The dirty washing water escapes through the valve E, and discharges at K into a drain.

Provision is also made (if required) for occasional washing of the prefilter with an upward flushing, by closing the valve E, and opening a flushing valve (not shown) on the unfiltered water-pipe above valve A. After the washing operation, which occupies from ten to fifteen minutes only, the filter is set to work again by closing valves D and E and opening valve A, the valve B remaining open. The drain valve C is always kept closed, except when it is required to empty the filter of water. It is only while the filter is being cleaned that the handle F is rotated and the water issues from the scour arms. The water-pressure required for the hydraulic scours is from 20 to 35 feet, and for the reversed upward "flow" the pressure required is from 6 to 10 feet. Gauges are provided so that the attendant can see at once when the most effective pressure is obtained.

Unfiltered water can be used for the hydraulic scours. The water used for the reversed upward flow should be filtered

water. When in working operation, the unfiltered water enters the filter through the pipe connected to the top dome, and, after passing through the two filtering-beds, flows away,

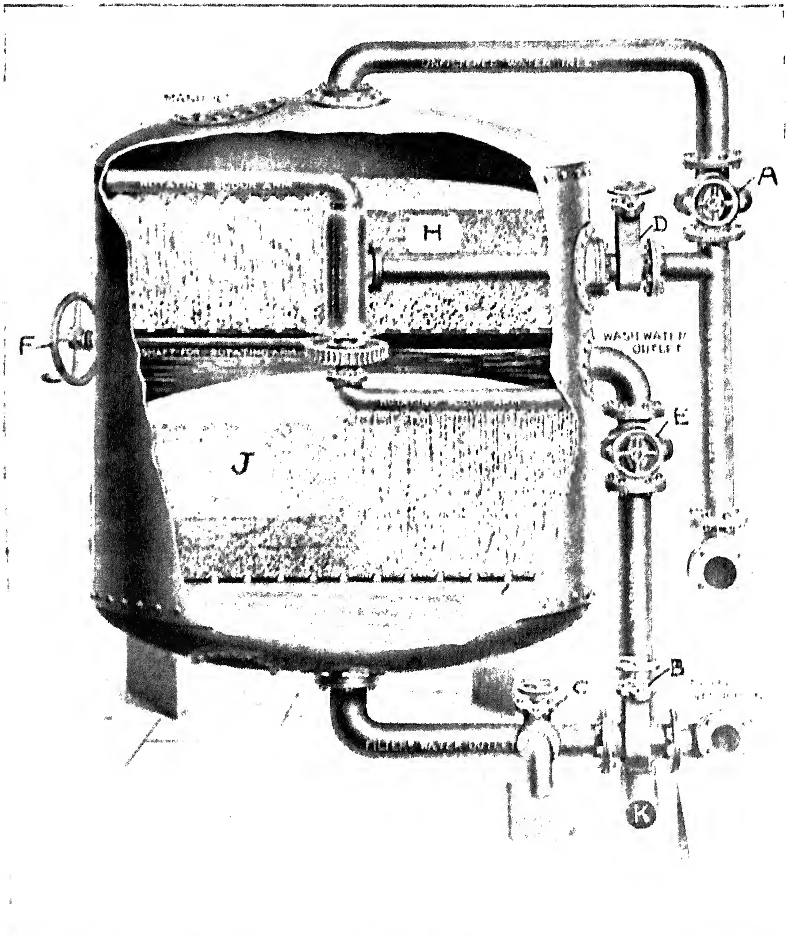


FIG. 101.—CANDY PATENT COMPOUND FILTER.

Valve A controls inlet of unfiltered water to the filter; valve B controls outlet of filtered water from the filter, also inlet of filtered water to filter for the upward wash; valve C is for emptying filter of water, when required; valve D controls inlet of water to the hydraulic scour arms; valve E controls outlet of dirty wash water; the mouth of the wash water pipe is shown at K; F is the handle by which the scour arms are rotated; H is the coarse prefilter resting on a perforated floor; J is the fine filter bed resting on a floor furnished with special gun-metal nozzles.

in a purified condition, through the pipe connected to the bottom dome.

For those cases where the water to be filtered does not require chemical treatment, and contains *but small quantities of suspended matter*, single bed-filters with the hydraulic scour system of cleansing are to be preferred. These may be scoured with compressed air and water. Polarite is applied in the ordinary Candy filter in addition to layers of sand (see p. 191).

The valves are arranged in the front of the filter and at a convenient height, while pressure gauges are supplied, so arranged as to indicate when the filter requires cleaning, and to show the correct pressure for this operation. A special calibrated indicator, termed an "index regulator," tells the quantity of water that the filter is dealing with, and enables the attendant to regulate a battery of filters so that each is always dealing with its proper volume. Provision is also made to plainly show the "wash water," in order that the attendant may see when the cleansing operation is completed.

As regards the addition of chemicals, the *patent "hydro-pneumatic" injector*, which operates without working parts, enables a solution of any required chemical to be automatically injected into the water-main. This injector works in conjunction with a "venturi" tube, so that the chemical solution is automatically added proportionately to variations in the flow.

Where the water calls for the use of chalk or lime, these reagents are added by means of small special phosphor-bronze plunger pumps, driven from a turbine placed in the water-main; the same turbine may, in large installations, be employed to turn the hydraulic scours when the filters are being cleaned.

The Ransome Continuous Filter.—To meet one of the chief objections to the slow sand-filter—namely, that it requires to be scraped or cleaned soon after it reaches its highest state of efficiency—the continuous sand-washing filter has been devised. The filtering-bed consists (1) of a stationary body of sand, B, resting upon a perforated plate, D, and partly maintained in position by a conical holder or bucket; and (2) of a moving layer, K, which is carried down by gravitation over the somewhat steep slope, S, of the stationary material towards the washing chamber (Fig. 102, O). From there it is passed on to the pipe,

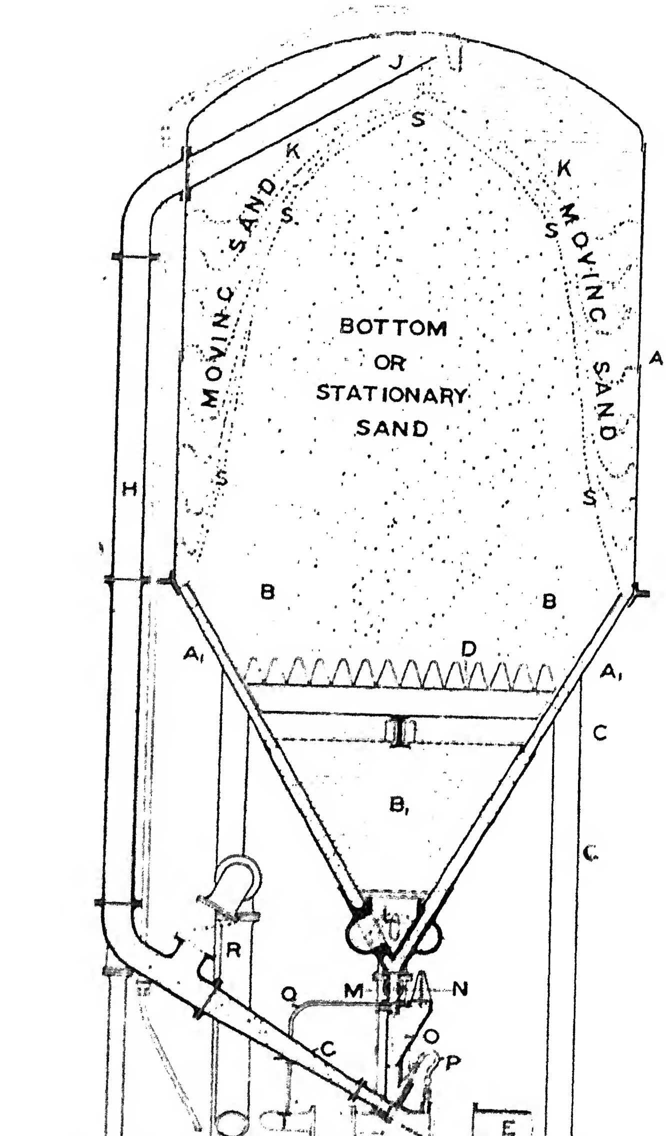


FIG. 102.—RANSOME CONTINUOUS FILTER.

E, which brings in the raw water. This pipe is contracted to a throat, F at the point where the sand enters, and afterwards ascends by the pipe H to the filter at J. The current conveys

the washed sand along with it, and distributes it on the top of the moving bed. This operation of sand-washing, and subsequent return of the washed granules along with the inflow, goes on continuously and without disturbing the stationary bed, which preserves the conical outline seen in the figure, considerably steeper than the natural angle of repose.

This filter has been installed at Merthyr Tydfil for dealing with a large supply. Sulphate of alumina is employed as

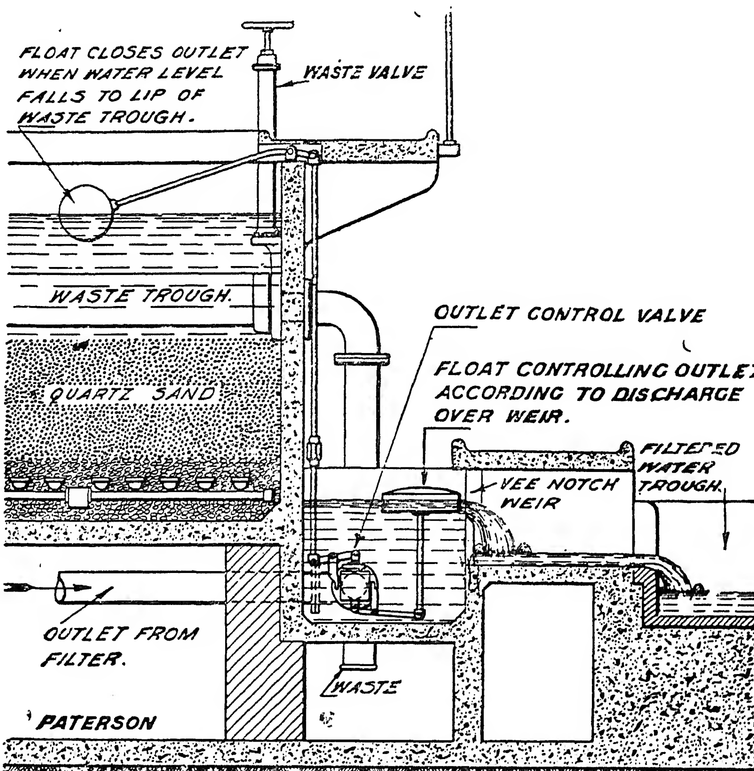


FIG. 103.—PATERSON AUTOMATIC OUTLET CONTROLLER.

coagulant, the raw water being from moorland and containing much organic matter. The germ content is not large, but *B. coli* is discoverable as a rule in 10 cm^3. The water is often much discoloured. On the other hand, the treated water is free from *B. coli*, and very few bacteria of any kind escape. The colour is rendered normal, and albuminoid matter reduced

to one-third. The stationary bed of filtering material requires washing at fairly long intervals, probably after six weeks' operation, as the raw water holds little solid matter in suspension.

PATERSON'S AUTOMATIC OUTLET CONTROLLER.

The importance of suspending the flow from a mechanical filter after washing has been already referred to (p. 164).

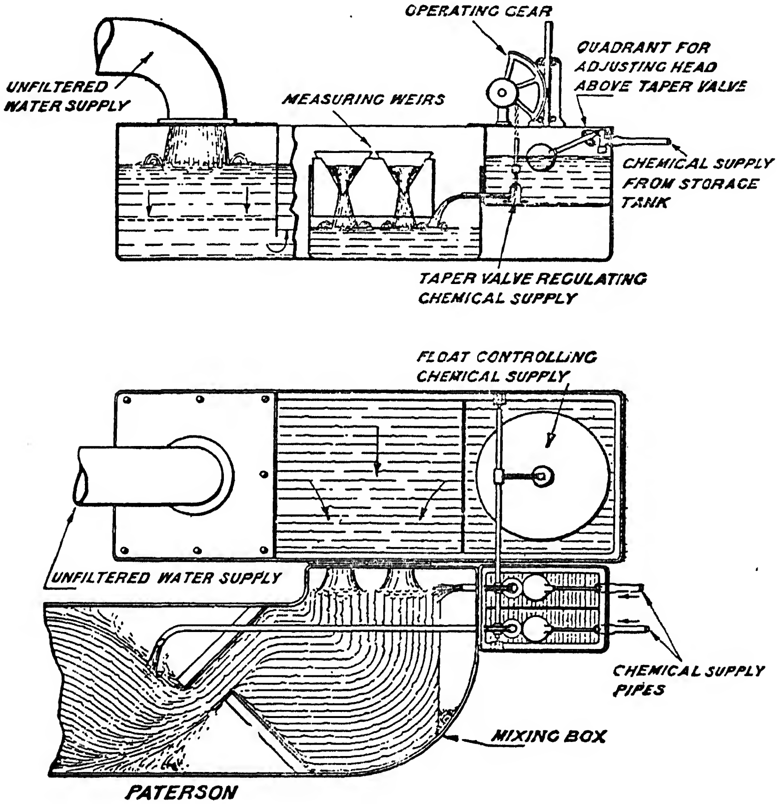


FIG. 104.—PATERSON AUTOMATIC MEASURING AND CHEMICAL SUPPLY GEAR (WEIR TYPE).

Paterson's outlet controller is a device for accomplishing this automatically. Essentially it consists of a valve under the double control of two floats, one riding upon the water in the filter itself, while the other is placed in the outlet chamber (Fig. 103). When the washings have been discharged from

the filter, and the supply again turned on, the first of the two floats is in such position that it keeps the outlet valve shut. As the cylinder fills, the float rises and gradually opens the outlet. Only when the level has reached a certain height, which may be adjusted to suit circumstances, does the control of this float cease, after which the rate of filtration is regulated by the second float in the outlet chamber.

PATERSON'S AUTOMATIC MEASURING AND CHEMICAL SUPPLY GEAR.

In this apparatus (Fig. 104) a float on the surface of the incoming water regulates the position of two tapered valves

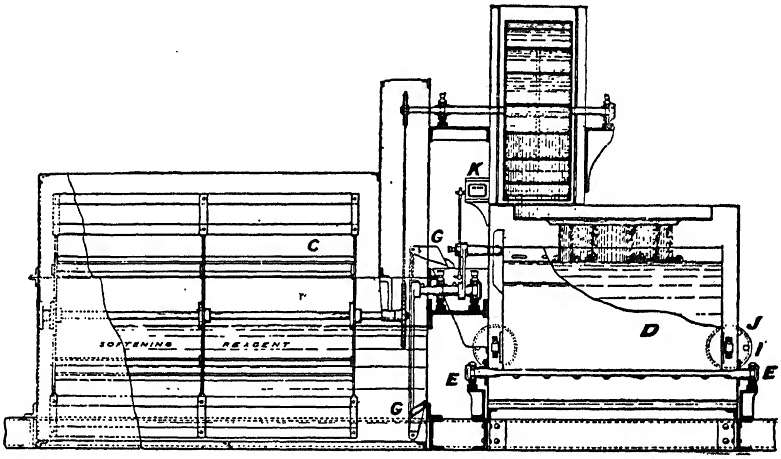


FIG. 105.—PATERSON OSILAMETER

of special form, which direct the flow of reagents through annular orifices in precise ratio to the volume of water passing. The "head" in the chemical tank is kept constant by means of ball-cocks on the conduits from the store or mixing tanks. At Cheltenham, where there is a large installation of Paterson filters, the chemicals are maintained at uniform strength by agitation with compressed air.

Paterson's Osilameter is represented in Fig. 105. The water on entering moves the tipper, D, which oscillates from side to side, and at each turn lifts a portion of the fluid frcm the chemical tank, C, by means of the buckets, G, and discharges

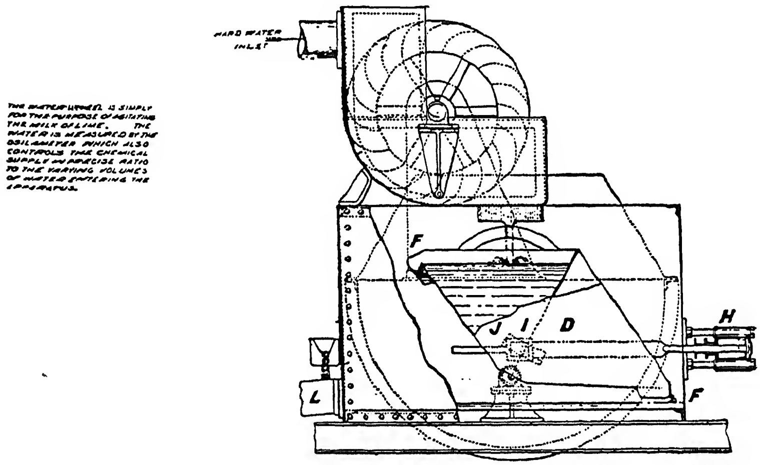
it into the supply. The water-wheel seen above drives a stirring gear. This apparatus is widely used in connection with water softening.

The Paterson Pressure Gear (Fig. 106) is designed to apply chemicals direct to the water-main.

Paterson Gravity Filters have recently keen ordered for Clydebank (4,000,000 gallons daily) and Scarborough (2,000,000 gallons daily).

Sterilization by Storage.

Provided we are satisfied to accept a restricted definition of the term "sterilization," and to regard water as being sufficiently sterilized when all pathogenic microbes are eliminated,



Measuring and Chemical Supply Gear.

then we need not hesitate to include storage in the list of agencies which render polluted waters sterile ; for it has been proved that the germs of those diseases which are liable to be communicated by drinking-water become extinct after a few weeks' retention in the reservoir. It has been stated (p. 25) that the typhoid bacillus has a life of seven weeks at most in water stored under laboratory conditions. The bacilli experimented with were first "cultivated" on a nutrient medium, and the indoor conditions of storing were not, perhaps, quite comparable with those which hold for reservoirs out of doors. In Dr. Houston's Seventh Report of Research Work,

all the circumstances relating to the tests made are seen to be very similar to those actually occurring in practice with stored waters. In the first place, the typhoid bacilli were taken direct from an infected person, and were therefore "uncultivated"; secondly, the storage was made in two large tanks containing 350 gallons of water, situated in the open air and surrounded by suitable fencing. One tank received a charge of cultivated, the other of uncultivated, *B. typhosus*. By repeated experiments it was found that the "uncultivated"

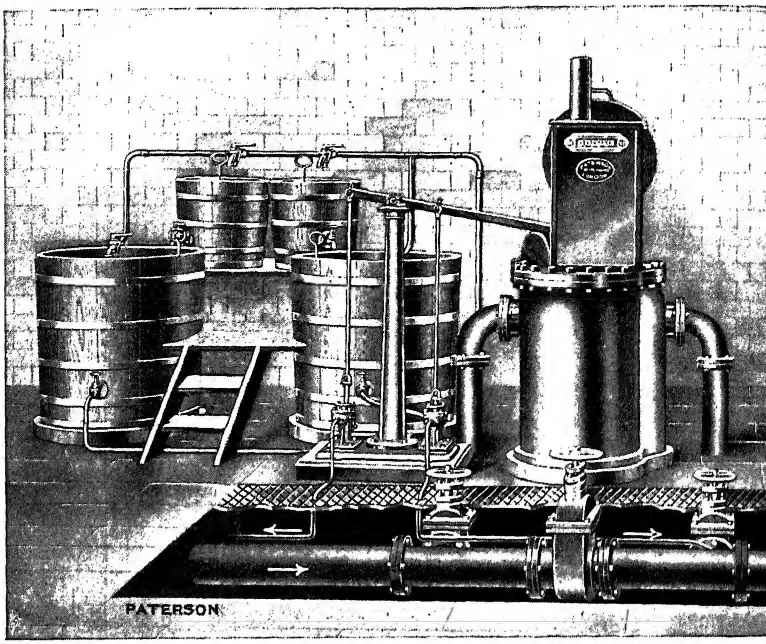


FIG. 106.—PATERSON PRESSURE CHEMICAL SUPPLY GEAR.

bacilli die much more speedily than the "cultivated." Possibly the range of experimental work has not yet been wide enough to enable one to fix a definite limit to the life of uncultivated *B. typhosus* in stored water, but at least it can be said that in stored Thames water they practically become extinct in three weeks. This time limit applies to the vitality of the bacillus in cold weather, when, as Dr. Houston also has shown, the period of its life is longer than in the warmer season. At a temperature ranging from 48° to 70° F., no *B. typhosus* could

be found in 100 cm^3. of the water, which had been heavily inoculated one week previously. Even cultivated typhoid bacilli in Thames water, stored under laboratory conditions at 50° F. or above, do not survive beyond four weeks. Experiments made by Major W. H. Horrocks and by Drs. J. C. Morgan and Harvey support the conclusions here set forth. Storage is more effective in warm weather than in cold, but Dr. Houston is satisfied that, in general, thirty days' storage of raw Thames water "is tantamount to sterilization, so far as the microbes associated with water-borne epidemic diseases are concerned."

One must not, however, conclude that storage, as we find it usually in operation, is to be entrusted with the whole duty of freeing polluted water from objectionable microbes; for even if a reservoir is capable of holding a hundred days' supply, one cannot be certain that the water which flows out has, at any particular time, been as long as two or three weeks impounded. But preliminary storage makes any subsequent process of purifying the water a simpler matter, and should it happen that from any cause this subsequent treatment failed temporarily to do its duty, there would still be satisfaction in knowing that storage had rendered the supply far safer —even, perhaps, entirely safe.

In relation to this discussion, it is of interest to note that the water-supplies drawn from the Great Lakes of Canada and the United States are almost certainly responsible for the high mortality from typhoid in such places as Duluth (57 per 100,000), Toledo (40), Ashtabula (86), Buffalo (21). Not that these vast bodies of water are incapable of oxidizing the sewage which is allowed to flow into them, but currents bring impure waters towards the intakes, and at times the condition of the service water is very different from what it would be if such currents did not exist. For this reason the city of Chicago diverted its sewage from the lake, and the intake of the supply water is far removed from all sources of pollution. The mortality from typhoid there now stands at 15 per 100,000.

APPENDIX

FILTRATION CONSTANTS AND DATA

1 cubic foot of water contains 6·23 gallons.
1 cubic yard of water contains 168 gallons.
1 cubic metre of water contains 220 gallons.
1 gallon of water weighs 10 pounds.
1 cubic foot of water weighs 62·3 pounds.
1 gallon = $4\frac{1}{2}$ litres.

Rate of Filtration.—

4 inches per hour = 10 centimetres (cm.) per hour.

And this corresponds to—

8 feet per day, or to 2·4 metres per day ;

or to—

8 cubic feet of water (*i.e.*, 50 gallons) per square foot per day ;

or to—

2·4 cubic metres (*i.e.*, 528 gallons) per square metre per day ;

or to—

2,175,000 gallons per acre per day.

Every inch of speed per hour corresponds to an output of 544,000 gallons per acre per day.

Each centimetre of speed of filtration per hour corresponds to an output of 0·24 cubic metre (52·8 gallons) per square metre per day.

Rainfall.—One inch of rain corresponds to 22,650 gallons per acre. Supposing that 40 per cent. of the rainfall is collected over an area of 100 acres, the daily supply per inch of rain, per annum, amounts to 2,480 gallons.

A rainfall of 36 inches over a collecting ground of 1 square mile would, under the same conditions, yield 572,000 gallons per day.

TABLE A.—Waste of Water by Taps left running.

Head of Water in Feet.	Loss from a $\frac{1}{4}$-Inch Pipe (Gallons per Hour).	Loss from a $\frac{1}{2}$-Inch Pipe (Gallons per Hour).	Loss from a $\frac{3}{4}$-Inch Pipe (Gallons per Hour).	Loss from a 1-Inch Pipe (Gallons per Hour).
5	130	520	1,150	2,050
10	185	750	1,650	2,800
15	225	900	2,000	3,550
20	260	1,040	2,300	4,100
25	285	1,150	2,600	4,650
30	320	1,290	2,860	5,080
40	370	1,500	3,300	5,600
50	408	1,645	3,620	6,660
60	450	1,800	4,000	7,100
80	520	2,080	4,600	8,200
100	570	2,300	5,200	9,300

E B.—Pressure of Water in Pounds per Square Inch for Various Depths.

r	Pressure per Square Inch.	Feet of Depth or Head.	Pressure per Square Inch.	Feet of Depth or Head.	Pressure per Square Inch.
	0·22	24	10·39	46	19·92
	0·43	25	10·82	47	20·35
	0·86	26	11·26	48	20·79
	1·30	27	11·65	49	21·22
	1·73	28	12·12	50	21·65
	2·16	29	12·55	55	23·82
	2·59	30	12·99 (13 nearly)	60	25·99 (26 nearly)
	3·03	31	13·42	65	28·15
	3·46	32	13·86	70	30·32
	3·89	33	14·29	75	32·48
	4·33	34	14·72	80	34·65
	4·76	35	15·16	85	36·82
	5·20	36	15·59	90	38·98
	5·63	37	16·02	95	41·15
	6·06	38	16·45	100	43·3
	6·49	39	16·89	125	54·00
	6·93	40	17·32	150	65·00
	7·36	41	17·75	175	76·00
	7·79	42	18·19	200	86·60
	8·22	43	18·62	300	130·00
	8·66	44	19·05	1,000	433·00
	9·09	45	19·49		
	9·53				
	9·96				

E C.—Loss by Friction in Water Pipes expressed in Pounds Square Inch for each 100 Feet of Length of Iron Main.

Size of Pipe (Inches Diameter).								
1.	1½.	2.	2½.	3	4.	6.	10.	12.
3	0·5	—	—	—	—	—	—	—
12	1·6	0·5	—	—	—	—	—	—
27	3·7	0·9	—	—	—	—	—	—
48	6·5	1·5	—	—	—	—	—	—
—	10·0	2·5	0·8	0·35	—	—	—	—
—	22·0	5·3	1·8	0·75	—	—	—	—
—	39·0	9·5	3·2	1·3	0·3	—	—	—
—	—	21·0	7·0	2·9	0·7	—	—	—
—	—	38·0	12·5	5·0	1·2	—	—	—
—	—	—	28·0	11·0	2·7	0·4	—	—
—	—	—	—	19·0	4·7	0·7	—	—
—	—	—	—	31·0	7·5	1·0	—	—
—	—	—	—	—	—	2·2	0·2	—
—	—	—	—	—	—	4·0	0·3	0·1
—	—	—	—	—	—	—	1·2	0·5
—	—	—	—	—	—	—	—	1·1

TABLE D.—Discharge of Pipes running full in Gallons per Minute.

Average Gradient of the Pipe.	Diameter of the Pipe in Inches.											
	1.	1½.	2	2½	3	4.	5.	6	7.	8.	9.	10.
1 foot in 5	12	34	70	123	190	400	700	1,100	1,600	2,300	3,000	3,900
1 ,, 10	9	24	50	87	140	280	490	780	1,100	1,600	2,100	2,800
1 ,, 12	8	22	45	79	—	—	—	—	—	—	—	—
1 ,, 14	7½	21	42	74	—	—	—	—	—	—	—	—
1 ,, 15	—	—	—	—	110	230	400	630	930	1,300	1,750	2,300
1 ,, 16	7	19	39	69	—	—	—	—	—	—	—	—
1 ,, 18	6½	18	37	65	—	—	—	—	—	—	—	—
1 ,, 20	6	17	35	61	100	200	350	550	800	1,100	1,500	2,000
1 ,, 30	5	14	29	50	80	160	280	450	660	920	1,230	1,600
1 ,, 40	4½	12	25	43	68	140	250	390	570	800	1,100	1,400
1 ,, 50	4	11	22	39	60	125	220	350	510	710	950	1,240
1 ,, 60	3½	10	20	36	55	115	200	315	470	650	870	1,140
1 ,, 80	3	8½	17	31	50	100	175	275	400	560	760	980
1 ,, 100	2¾	7½	16	28	43	90	155	245	360	500	675	880
1 ,, 125	2½	6¾	14	24	40	80	140	220	320	450	605	785
1 ,, 150	2¼	6¼	13	22	36	72	127	200	295	410	550	720
1 ,, 200	2	5½	11	19	31	62	110	170	260	350	480	620
1 ,, 250	1¾	4¾	10	17	27	56	100	150	230	320	425	550
1 ,, 300	1½	4½	9	16	25	50	90	140	210	290	390	510
1 ,, 400	—	—	—	—	21	43	78	120	180	250	320	415
1 ,, 500	—	—	—	—	19	40	69	110	160	225	300	390
1 ,, 600	—	—	—	—	18	36	63	100	150	205	275	360
1 ,, 800	—	—	—	—	16	31	55	87	130	175	240	320
1 ,, 1,000	—	—	—	—	14	28	49	78	115	160	215	280

TABLE D.—Discharge of Pipes running Full in Gallons per Minute—*continued.*

Average Gradient of the Pipe.	Diameter of the Pipe in Inches.						
	12.	15.	18.	21.	24.	30.	36.
1 foot in 20 ..	3,000	5,400	8,500	12,500	17,500	30,000	48,000
1 ,, 30 ..	2,500	4,400	7,000	10,250	14,300	25,000	39,000
1 ,, 40 ..	2,200	3,800	6,000	8,900	12,400	21,600	34,000
1 ,, 60 ..	1,800	3,100	4,900	7,250	10,100	17,700	27,900
1 ,, 80 ..	1,550	2,710	4,250	6,300	8,750	15,300	24,200
1 ,, 100 ..	1,390	2,400	3,800	5,600	7,850	13,700	21,600
1 ,, 125 ..	1,240	2,160	3,400	5,000	7,000	12,250	19,300
1 ,, 150 ..	1,130	1,980	3,100	4,600	6,400	11,200	17,600
1 ,, 200 ..	980	1,700	2,700	4,000	5,500	9,700	15,300
1 ,, 300 ..	800	1,400	2,200	3,250	4,500	7,900	12,500
1 ,, 400 ..	690	1,200	1,900	2,810	3,900	6,850	10,800
1 ,, 500 ..	620	1,100	1,700	2,500	3,500	6,130	9,700
1 ,, 750 ..	505	880	1,390	2,050	2,870	5,000	7,900
1 ,, 1,000 ..	440	765	1,200	1,775	2,480	4,330	6,840
1 ,, 1,500 ..	360	625	985	1,450	2,030	3,535	5,580
1 ,, 2,000 ..	310	540	850	1,255	1,750	3,060	4,840

TABLE E.—Water-Supply by Gravitation.

DIMENSIONS OF MAINS, STORAGE RESERVOIR, AREA OF GATHERING GROUND.

Population.	Daily Supply at 40 Gallons per Head.	Gallons per Minute, reckoning 12 Hours only per Day steady Flow.	Diameter of Main in Inches, with a Gradient of 1 in 100.	Area of the Gathering Ground, assuming 10 Inches of Rainfall actually collected.	Area of Storage Reservoir for 100 Days' Supply.	Area of Filter Bed at 4-Inch Rate per Hour, allowing for spare Area
1,000	40,000	56	4	90 acres	1¼ acres; average depth of 12 feet	125 square yards
20,000	800,000	1,111	12	1,800 ,,	25 acres; average depth of 12 feet	½ acre
50,000	2,000,000	2,778	17	4,600 ,,	62½ acres; average depth of 12 feet	1¼ acres
100,000	4,000,000	5,556	21	9,200 ,,	125 acres; average depth of 12 feet	2½ acres

In calculating the area of the gathering ground it is assumed that 10 inches (being a percentage of the total rainfall) is collected, and a margin of 40 per cent. is added in case of exceptional periods of drought.

TABLE F.—Discharge of Water over Weirs per Lineal Foot at varying Depths in Gallons per Minute.

Depth in Inches.	Gallons per Lineal Foot of Width per Minute.	Depth in Inches.	Gallons per Lineal Foot of Width per Minute.	Depth in Feet.	Gallons per Lineal Foot of Width per Minute.
½	11	4½	306	1	1,332
1	32	5	358	1¼	1,860
1¼	46	5½	413	1½	2,447
1½	59	6	471	1¾	3,083
1¾	74	6½	531	2	3,767
2	90	7	593	2½	5,264
2½	126	8	725	3	6,920
3	166	9	865	4	10,655
3½	210	10	1,013	5	14,892
4	256	11	1,169	6	19,572

The above table applies to the case of discharge over weirs from still water. If, however, the weir be placed in a current, an addition must be made to the depth of the weir in accordance with the next table. Thus, supposing that the weir is 2 inches deep, and that the current flows towards it at the rate of 94 feet per minute, an addition of ½ inch is to be made to the depth of the weir in reading the discharge, so that instead of 90 gallons we take 126 gallons, corresponding to a depth of 2½ inches.

TABLE G.—Velocities in Open Channels corresponding to Various Heads.

Head in Inches.	Velocities in Feet per Minute.	Head in Inches.	Velocities in Feet per Minute.	Head in Inches.	Velocities in Feet per Minute.
⅛	47	⅞	125	2½	210
¼	66	1	133	3	230
⅜	82	1¼	156	4	270
½	94	1½	163	5	300
⅝	105	1¾	177	6	330
¾	115	2	186		

TABLE H.—Strength of Lead Pipes and Weight per Lineal Foot.

Diameter of Pipe in Inches.	Weight in Pounds per Foot.	Safe Pressure in Pounds per Sq. In.	Diameter of Pipe in Inches.	Weight in Pounds per Foot.	Safe Pressure in Feet of Water (Head).
½	2·3	225	1¼	7·0	150
⅝	3·1	180	1½	9·0	140
¾	4·0	170	1¾	10·3	120
1	5·3	150	2	11·0	115

NOTE.—These figures refer to pipes of medium thickness.

TABLE K.—Strength and Weight of Iron Pipes and Thickness of Metal sufficient to support Different Pressures.

Diameter of Pipe in Inches.	Head of 100 to 150 Feet.		Head of 150 to 300 Feet.		Head of 300 to 500 Feet.	
	Thickness in Inches.	Weight per Yard.	Thickness in Inches.	Weight per Yard.	Thickness in Inches.	Weight per Yard.
		cwt. qr. lb.		cwt. qr. lb.		cwt. qr. lb.
2	0·29	0 0 24	0·31	0 0 26	0·34	0 1 0
3	0·32	0 1 5	0·34	0 1 9	0·38	0 1 14
4	0·34	0 1 22	0·38	0 1 26	0·43	0 2 5
5	0·38	0 2 14	0·43	0 2 21	0·5	0 3 4
6	0·38	0 2 21	0·43	0 3 5	0·5	0 3 21
7	0·43	0 3 24	0·5	1 0 8	0·56	1 1 0
8	0·43	1 0 12	0·5	1 1 0	0·56	1 1 20
9	0·5	1 1 12	0·56	1 2 2	0·62	1 2 22
10	0·5	1 2 0	0·56	1 2 22	0·62	1 3 14
12	0·56	2 0 0	0·62	2 0 25	0·70	2 1 21
15	0·63	2 3 7	0·70	3 0 10	0·88	3 2 14
18	0·70	3 2 0	0·75	4 0 0	0·94	4 3 21
21	0·70	4 1 0	0·8	5 0 0	1·00	6 1 14
24	0·75	5 1 0	0·88	6 1 0	1·10	8 0 0
30	0·88	7 3 14	1·00	8 3 21	1·30	11 1 0
36	1·00	10 2 21	1·10	11 2 14	1·50	15 3 14

NOTE.—0·29 inch $=\frac{9}{32}$ inch nearly ; 0·31 $=\frac{5}{16}$; 0·34 $=\frac{11}{32}$; 0·38 $=\frac{3}{8}$; 0·43 $=\frac{7}{16}$; 0·56 $=\frac{9}{16}$; 0·62 $=\frac{5}{8}$; 0·70 $=\frac{11}{16}$; 0·81 $=\frac{13}{16}$; 0·88 $=\frac{7}{8}$; 0·94 $=\frac{15}{16}$.

TABLE L.—Approximate Cost of Sand Filtration, Purification by Ozone, and the De Chlor Process.

UNIT OF QUANTITY CONSIDERED : 1,000,000 GALLONS PER DAY.

	Sand Filters.	Ozone.	De Chlor.
Capital outlay ..	£7,000 to £10,000 per acre	£4,000, not including site or buildings	£2,000
Filtering area ..	About $\frac{3}{4}$ acre	For rough filtration, $\frac{1}{2}$ acre	Rough filtration is generally required
Maintenance (not including interest)	6s. to 12s., average of a large number of stations, 6s. 6d.	30s. to 60s., according t quality of raw water and electrical supply available	Cost of chemicals only, 1s. 10d.

TABLE M.—Comparative Cost (Approximate) of Various Filters, with regard to Capital Outlay and to Working Expenses.

(Taken by permission of the Council of the Inst. Mech. Eng. from Proc., Jan. 1909, with modifications.)

UNIT OF QUANTITY CONSIDERED : 1,000,000 GALLONS PER DIEM.

No service reservoir is supposed to exist, and the cost of such is not included in the estimates given here.

	Jewell.	Bell Bros.	Candy.	Puech.	Mather and Platt, Ltd.
Capital outlay (approx.)	£2,100.	£2,100.	£2,100.	£3,870.	£2,100.
Filtering area	454 sq. ft.	302 sq. ft.	318 sq. ft.	17,500 sq. ft.	364 sq. ft.
Mechanical power	10 B.H.P.	2 B.H.P.	None.	None.	None, unless desired.
Maintenance (not including interest)	10s.	10s.	2s.	10s.	Not definitely stated. May be about same as for Bell.
Filter washing, how often?	Once or twice daily.	Once daily to once in three days.	Same as Bell.	Part weekly. Part monthly. Part yearly.	Once per day as a rule.
Free run of the filter after washing	15 minutes.	With extra alum added, a few minutes.	A few minutes.	Time required to fill the filtering basins—*i.e.*, a few minutes.	3 to 5 minutes.
Percentage of water required for washing	2½ per cent.	1 per cent. or less, often ½ per cent.	½ per cent.	Varies with the condition of the raw water, 2½ to 3 per cent. as a rule.	About 2 per cent.
Life of the filter	50 years.	Equal to the life of a steel bridge.	50 years.	Equal to the life of slow-sand filters.	50 years as a minimum.
Arrangement for regulating the supply of any precipitant added	Special regulating taps are provided working under steady head.	A self-regulator is attached (see p. 179).	None required.	As a rule, no precipitant is employed. If necessary, a gauged tap is used.	Ball-valve regulator, or small pump from water motor on the main (see p. 153).

The above statistics may be accepted as substantially accurate, as they have been supplied through the kindness of the proprietors of the filters quoted.

Addenda on Costs, etc., of Filtering Apparatus.

The Puech-Chabal installation at Magdeburg was constructed at an average of £1,563 per unit of 1,000,000 gallons per day.

For Mather and Platt's filter 10 to 14 B.H.P. is required for a unit of 1,000,000 gallons per day, and the average percentage of wash-water runs from 0·5 to 1. The life of this filter is that of a steel tank. The coagulant is dealt with by a special automatic pump.

In the Candy filter injection of coagulant is made, if necessary, by an apparatus in connection with a Venturi tube.

The approximate capital outlay named in Table L for the De Clor process is on the assumption that the water has been previously filtered; a pre-filter combined with the De Clor filter will increase the cost by approximately £500.

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